NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

AN INVESTIGATION OF TWO-PROPELLER TILT WING V/STOL AIRCRAFT FLIGHT CHARACTERISTICS

by

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June, 1993

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b. OFFICE SYMBOL (If applicable) 55	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000	7b. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS Program Element No. / Project No. / Task No. / Work Unit Accession Number

11. TITLE (Include Security Classification)
AN INVESTIGATION OF TWO-PROPELLER TILT WING V/STOL AIRCRAFT FLIGHT CHARACTERISTICS

12. PERSONAL AUTHOR(S) Nieusma, William J. Jr.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (year, month, day)	15. PAGE COUNT
Engineer's Thesis	From To	June 1993	90

16. SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17. COSATI CODES			18. SUBJECT TERMS (continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUBGROUP	Tilt Wing V/STOL aircraft, TWANG, TLTWNG!!, Longitudinal Pitch Attitude, Longitudinal Stick position, Elevator position

19. ABSTRACT (continue on reverse if necessary and identify by block number)

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS REPORT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. Conrad F. Newberry	22b. TELEPHONE (Include Area code) (408) 646-2491 22c. OFFICE SYMBOL 31

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted
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SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

Approved for public release; distribution is unlimited.

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Submitted in partial fulfillment
of the requirements for the degree of

AERONAUTICAL AND ASTRONAUTICAL ENGINEER

from the
NAVAL POSTGRADUATE SCHOOL
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The results of a two-propeller tilt wing aircraft static stability and performance simulation utilizing a NASA-Ames computer code, Tilt Wing Application General (TWANG), are presented with comparisons to actual test flight data. The Canadair CL-84 tilt wing aircraft was used as a model for the geometric data utilized by the computer simulation. Aerodynamic data for the simulation were obtained from previous NASA Ames research related to a four-propeller model. Variables used included a wide range of parameters associated with flight conditions from hovering flight to maximum cruise speeds at several different altitudes and wing tilt configurations. Longitudinal pitch stability was the driving factor in determining aircraft static stability for the various flight conditions. Results of the simulation indicate that the TWANG computer code provides an accurate prediction of both generic and specific tilt wing aircraft static pitch performance characteristics, as well as the additional capability of providing the required mathematical parameters for incorporation into the NASA Ames Vertical Motion Simulator as software inputs.

TABLE OF CONTENTS

LIST OF FIGURES

ACKNOWLEDGEMENT

I would like to thank my advisor, Professor Conrad F. Newberry, for his advice and patience. I would also like to thank Professor Michael M. Gorman for the use of his laboratory facilities and Dr. Steven M. Ziola for his advice on technical documentation. Thanks also go to Dr. J. Victor Lebacqz for the opportunity to work with NASA Ames on this effort with a very bright group of people there: Mr. William Decker, Mr. William Hindson, Mr. Gary Churchill, Mr. Lloyd Corliss, Ms. Lourdes Guerrero, Mr. Joseph Totah, and Mr. Jerry White. Special thanks to Joe for showing me the way.

I. INTRODUCTION

The need for aircraft with the versatility to perform a multitude of missions, including troop transport, medivac, cargo, ASW, AEW, gunfire spotting, close air support, as well as civil applications such as executive transport and commuter carrier, was identified several decades ago [Ref. 1]. From these needs it was hoped that there would arise an aircraft with the short or vertical take off capability of a helicopter and the speed and range of an airplane. The two main configurations that have evolved are the tilt rotor and the tilt wing [Ref. 1]. Among the designs built and tested were the Boeing Vertol VZ-2, the Hiller X-18, the LTV XC-142A, and the Canadair CL-84 [Fig. 1]. All of these tilt wing aircraft were configured with a rotor or jet reaction device, located at the tail, for satisfactory handling qualities associated with pitch control.

Recent renewed interest in rotorcraft technology has led to the development of several designs of both tilt rotor aircraft (XV-15, V-22, Magnum civil tilt rotor) and tilt wing aircraft (Ishida TW-68). Hampering the development of these aircraft has been the lack of previous test flight data. The only test flight reports available for twin engine configured tilt wing aircraft are those for the CL-84 [Ref. 2]. NASA's High Speed Rotorcraft research group has recently

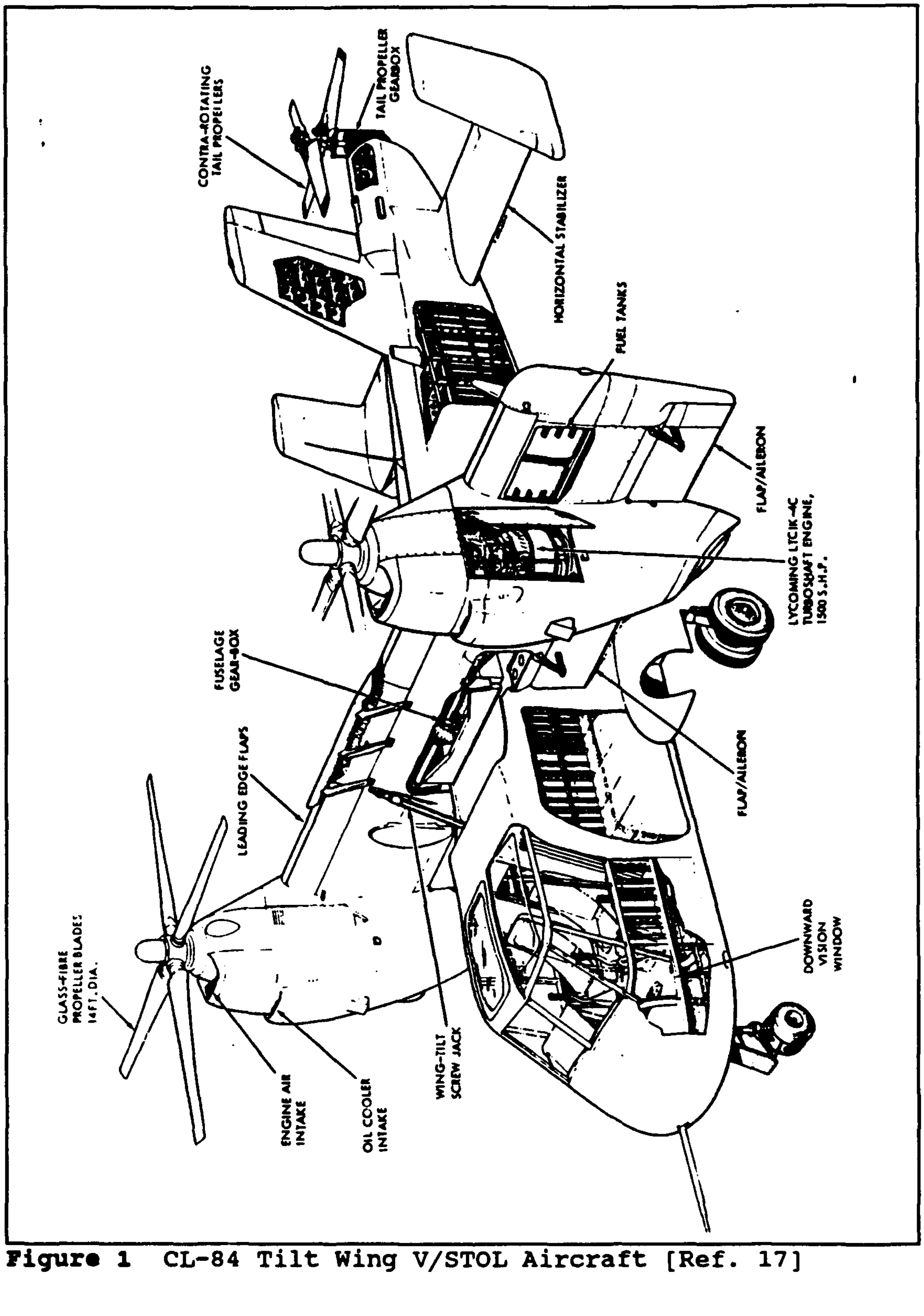


Figure 1 CL-84 Tilt Wing V/STOL Aircraft [Ref. 17]

conducted studies of a generic four-propeller configured tilt wing aircraft. This effort led to the development of a mathematical model of the tilt wing system [Ref. 3], as well as piloted simulations of a generic four-propeller tilt wing aircraft [Fig. 3] in the NASA Ames Vertical Motion Simulator (VMS) [Ref. 4]. A Macintosh computer-based code (TWANG) was used to predict initial aircraft performance parameters and handling qualities, as well as to provide values of aerodynamic forces, moments, and their corresponding coefficients. These were incorporated as input data into the VMS for the man-in-the-loop simulations of the tilt wing model [Fig 2].

Further research into alternative longitudinal control techniques was required in order to reduce or eliminate the tail thrust machinery. This would reduce aircraft complexity and weight, and enhance safety during ground operations. This effort led to the need for additional simulations involving a two-propeller configured aircraft. These additional simulations would evaluate the Churchill geared flap in a procedure parallel to the previously mentioned NASA Ames four propeller simulations. An initial TWANG based study of the CL-84 by the writer was conducted simulating actual aircraft configurations and flight test conditions. The results are compared with flight test data and reported herein. Aircraft static performance comparisons of the programmed flap control system were analyzed and comparisons are drawn to previous

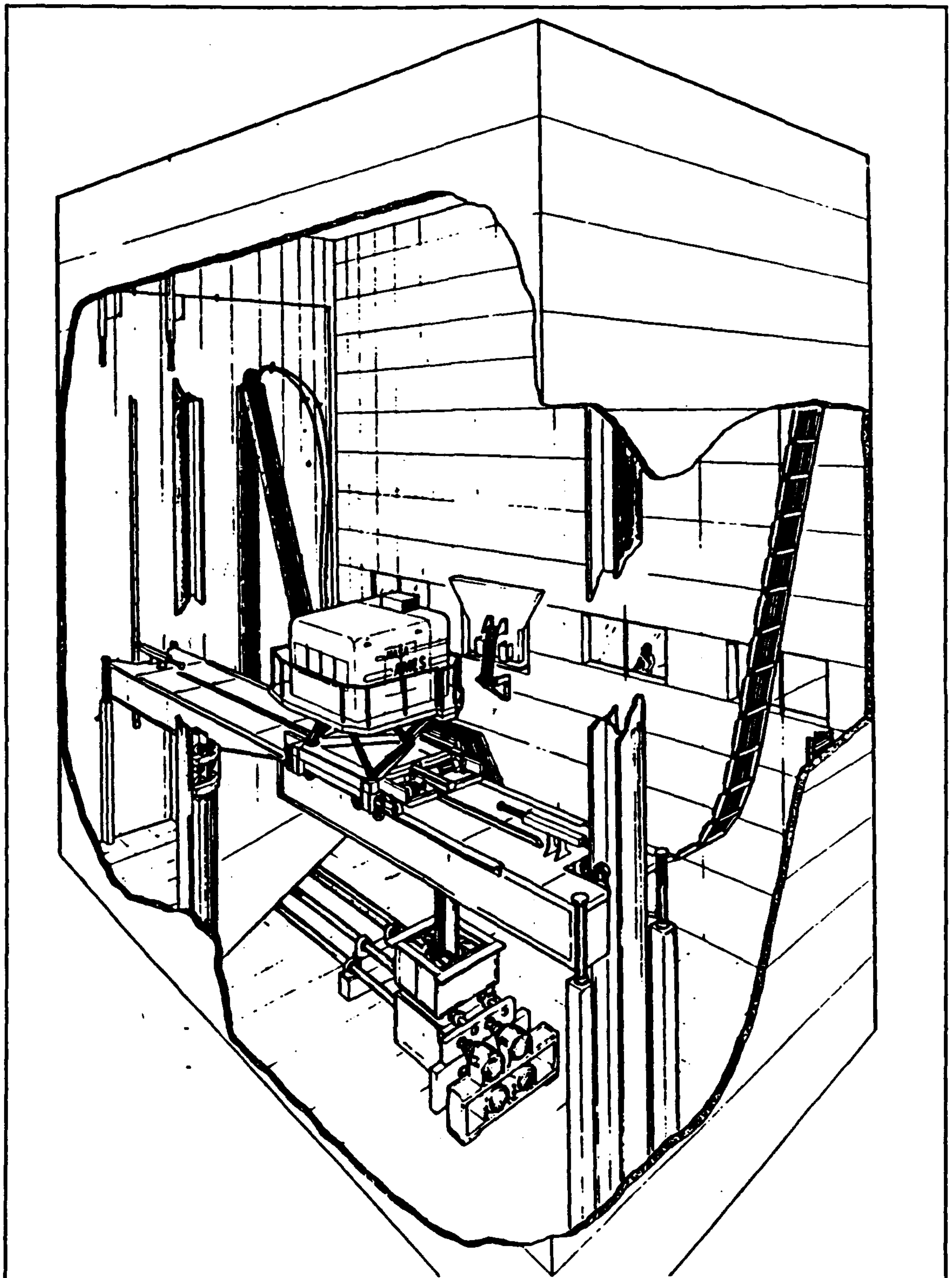


Figure 2 NASA Ames Vertical Motion Simulator [Ref. 5]

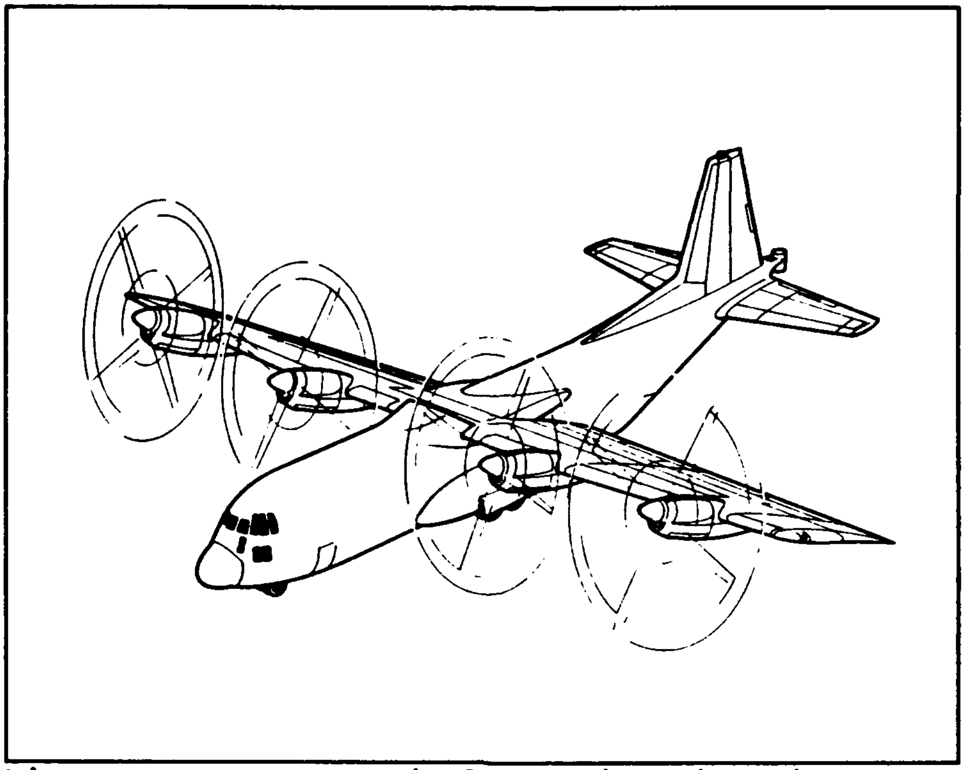


Figure 3 NASA Ames Simulated Tilt Wing Aircraft [Ref. 5]

Ames four- propeller tilt wing results as a means of validating the TWANG desk top program as a tilt wing design tool.

II. PREVIOUS RESEARCH

Starting in 1990, the NASA Ames Aircraft Technology Division directed study into the simulation of a medium transport-sized tilt wing aircraft. This interest had its origins in the U. S. Special Operation Forces, U. S. Air Force Advanced Theater Transport group, NASA High Speed Rotorcraft research, and civil applications. This new research was also spurred by technology advancements in materials, propulsion, and flight controls systems which were achieved in the years since the CL-84 aircraft was conceived. The advancements filled previous technology gaps in tilt wing technology and aid in predicting true performance unhindered by hardware shortcomings.

The objectives of this simulation study [Ref. 5] were to: 1) simulate a representative tilt wing aircraft, 2) compare the control effectiveness and handling qualities of programmed flap and geared flap control arrangements, and 3) determine the feasibility of eliminating the requirement for tail rotors or reaction jets for pitch control through the use of the geared flap arrangement [Ref. 5].

The aircraft simulated by NASA Ames [Fig. 3] was a medium transport aircraft configured with four propellers, weighing approximately 87,000 lb. with an overall length of 97 ft. Thirteen pilots participated in 119 runs on the Ames VMS.

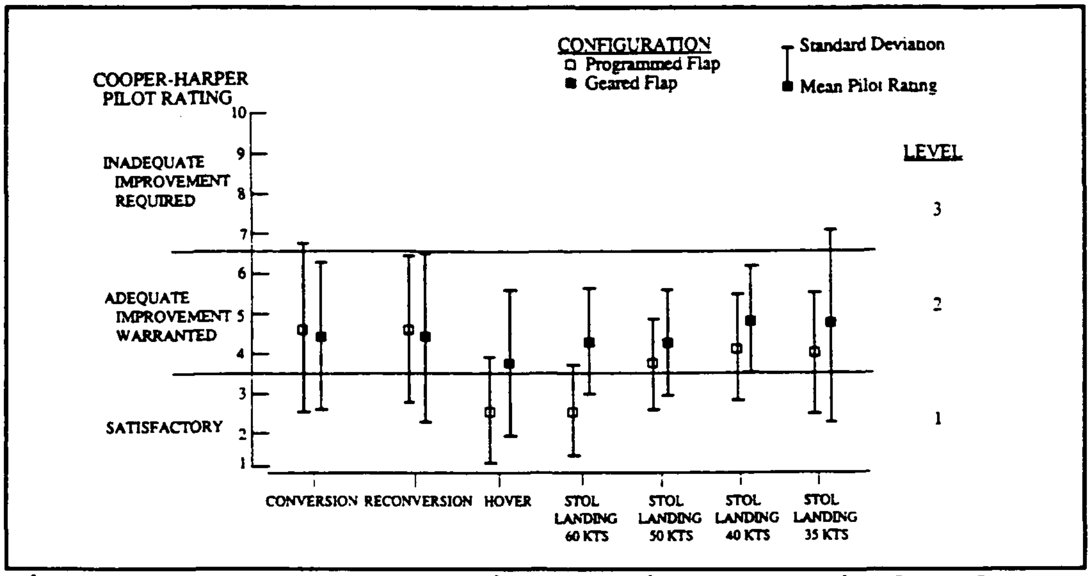


Figure 4 Cooper-Harper Pilot Ratings for Simulated Four Propeller Tilt Wing Aircraft [Ref. 5]

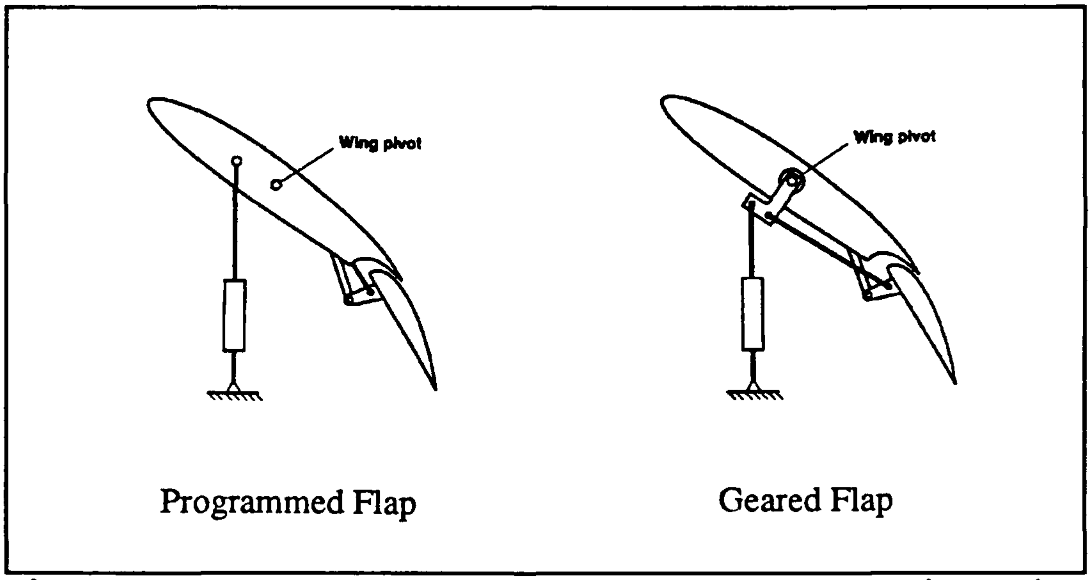


Figure 5 Programmed Flap and Geared Flap Wing Tilt Control Systems [Ref. 5]

Each pilot rated handling qualities according to the Cooper-Harper rating scale on each task performed [Fig. 4]. The simulations were conducted without ground effects modelling and used simple lateral-directional response and pitch-rate feedback for the longitudinal control system [Ref 5].

The conclusions resulting from this study were that the tilt wing simulation is valid for research purposes, that both the programmed flap and the geared flap control configurations demonstrated level 2 handling qualities (satisfactory - with room for improvements), and that the geared flap concept was feasible for tilt wing aircraft and, additionally, reduced the tail thrust required power compared to the programmed flap configuration. Recommendations for follow-on research included higher order control systems. The NASA Ames Tilt Rotor Steering Committee also recommended the addition of a ground effects airflow model and a twin propeller aircraft simulation to be included in possible additional research for 1992 - 1993. From the author's personal experience involving over 1300 hours of rotary wing aircraft flight time, operation of the simulator in a fixed-base mode was considered to be fairly simple. The pilot tasks were easily accomplished with the control configurations used by the simulation study pilots. The simulation was an excellent initial trainer for pilots inexperienced with tilt wing or tilt rotor cockpit layouts and control responses. Use and location of wing tilt angle indicator, power lever (vice helicopter collective), and wing tilt beep trim can be introduced to the first time V/STOL pilot. Hovering and conversion tasks are accomplished with a simple yet effective control response model contained within the present NASA Ames tilt wing code.

The CL-84 test aircraft was a technology demonstration platform combining tilt wing and deflected slipstream lift arrangement for V/STOL operations [Ref. 6]. Nominal gross weight for STOL flight is approximately 14,700 lb., while gross weight for VTOL flight is approximately 11,200 lb. Propulsion consists of two Lycoming LTK1-4C free turbine engines, each turning a 14 ft. diameter rectangular planform propeller. The engines are linked by cross-shafting and located in wing-mounted nacelles. Each engine had a maximum output flat rating of 1500 shaft horsepower (SHP) and a sea-level, standard day normal output rating of 1150 SHP. Fig. 6 shows the basic aircraft including some dimensions, while additional physical characteristics are found in Ref. 7. Fig. 7 displays the wing (i_w) and horizontal tail (i_t) incidence reference planes, along with representative center of gravity (CG) locations for the tilting system (wing), nontilting system (fuselage), and total aircraft. The wing has leading edge Krueger flaps and full-span single-slotted trailing edge flaps. Trailing edge flaps and tail incidence angle are programmed for deflection according to wing incidence angle. This arrangement provides for a level fuselage throughout most of the flight vehicle regime. Twin coaxial rotors at the tail provide fuselage pitch control in a hover. Yaw control in a hover is maintained by differential aileron deflection at

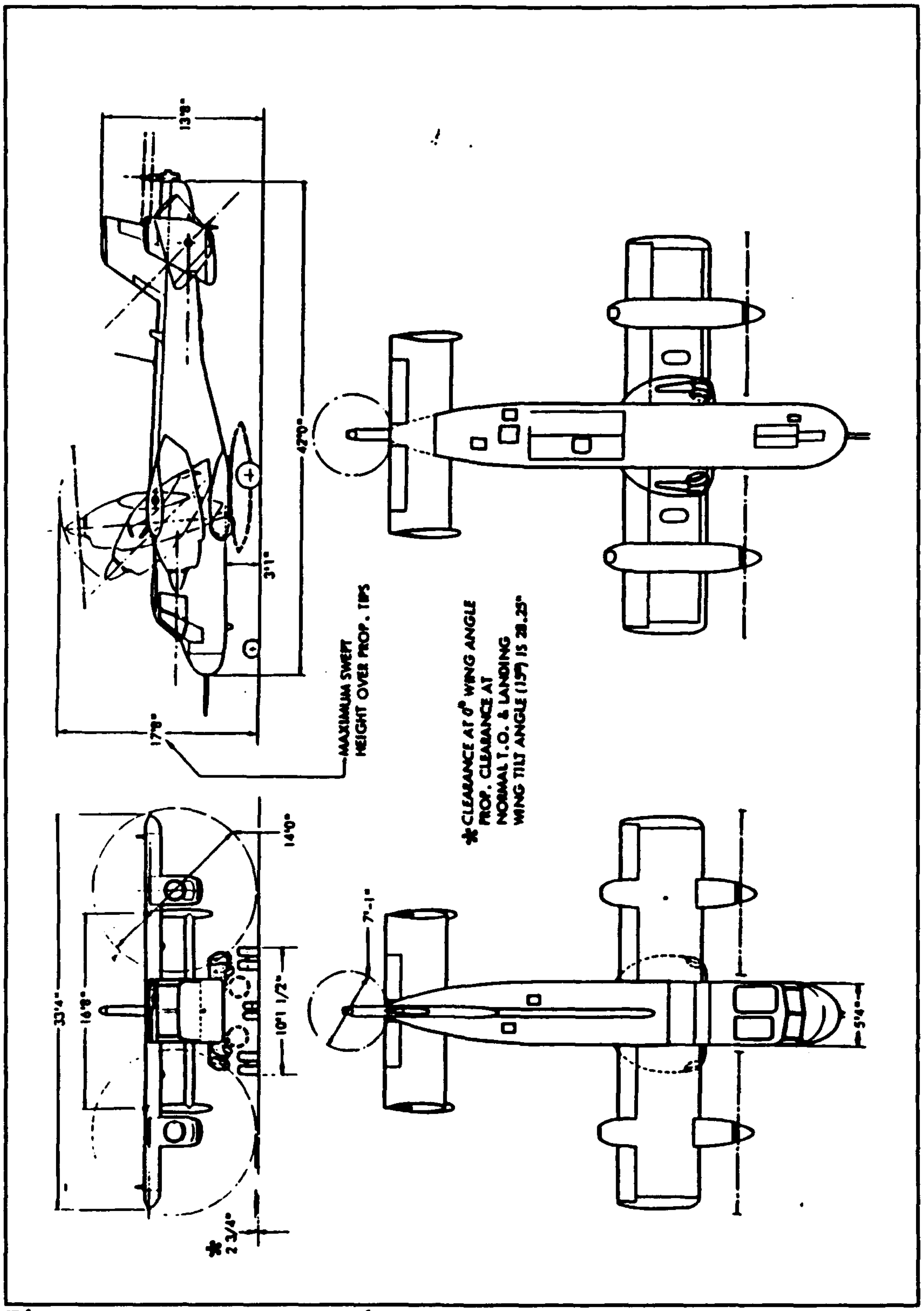


Figure 6 CL-84 Four View [Ref. 17]

large wing tilt angles. [Ref. 7]

To date, no tilt wing V/STOL aircraft has flown which did not require some type of tail rotor or reaction jet device to maintain pitch control during V/STOL operations. This is due to the fact that the wing, flaps, and elevators are ineffective without dynamic pressure from forward velocity. As vehicle airspeed builds, pitch control is gradually transferred to the elevators and the tail thrusting device is stopped. In addition to the pitch control during V/STOL operations, the tail propellers of the CL-84 aircraft provide substantial lift during hover and low speeds [Ref. 8].

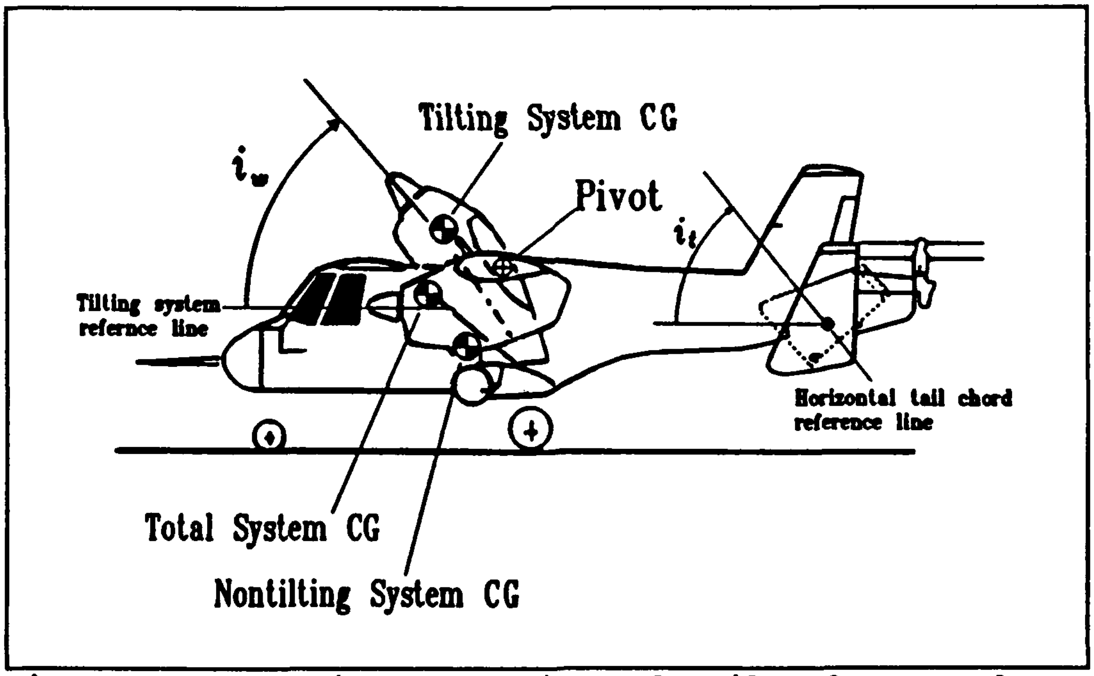


Figure 7 CL-84 Wing and Horizontal Tail Reference Planes

CL-84 flight testing was performed from the mid-1960's through the mid-1970's. Groups from the Royal Canadian Armed Forces, U. S. Army Aviation Laboratories, U. S. Naval Air Test Center, and NASA Langely Research Center, to name a few, conducted various test flights [Ref. 8]. The CL-84 is one of the few tilt wing platforms for which flight test data are available and the only two-propeller tilt wing platform from which V/STOL flight characteristics could be compared. Conclusions from flight testing were that the CL-84 was suitable for various utility missions, but unsuitable for military use due to shortcomings in materials, propulsion, and control characteristics at the time. Ref. 8 describes the deficiencies as conceptual and of a nature which can be corrected by hardware redesign.

III. ANALYTICAL PROCEDURE

A. TILT WING MATHEMATICAL MODEL

Ref. 3 provides the basis for the TWANG computer code's simulations with derivation of the tilt wing system equations of motion. Two pilot inputs, longitudinal stick position and wing tilt angle, are the outputs from the control laws , which command five inputs to the aircraft's longitudinal dynamic characteristics. These five input parameters are wing incidence (i_w), flap deflection (δ_f), horizontal tail deflection (δ_t), elevator deflection (δ_e), and tail jet thrust deflection (δ_{tj}). The aerodynamic forces acting about the pitch axis are functions of these five inputs, and the four equations of motion comprise the longitudinal mode state-space. A fourth longitudinal mode is created due to the presence of the tilting mass system inherent in the tilt wing aircraft. The tilting system is comprised of the wing and the thrust-producing devices (propellers), while the nontilting system is made up of the fuselage, empennage, landing gear, and tail jet device. Forces and moments for both tilting and nontilting mass systems are computed using coupled-body equations of motion in terms of four accelerations ($\dot{u}$, $\dot{w}$, $\dot{q}$, $\ddot{i}_w$). These equations are placed into a system as the longitudinal aircraft equations of motion about the total aircraft system center of gravity (CG), with variables $\dot{u}$, $\dot{w}$, $\dot{q}$, and $\ddot{i}_w$. The longitudinal aircraft state-space is shown in Appendix A. The accelerations of both the tilting system and nontilting system are calculated separately about their respective CG's, and accelerations of these CG's are calculated for a fixed reference frame in space. The accelerations are then resolved in terms of the four state components, e.g., $\dot{u}$, $\dot{w}$, $\dot{q}$, $\ddot{i}_w$. [Ref. 3]

B. TWANG TILT WING APPLICATION

TWANG (Tilt Wing Application General) is a FORTRAN computer code written by Gary B. Churchill of NASA Ames. In its present form TWANG requires 4,000,000 (4MB) bytes of memory and utilizes the Macintosh Programmer's Workshop (MPW) FORTRAN application software. TWANG is capable of either reading configuration and aerodynamic input files or using manual input data. The output provides static aircraft longitudinal parameters for determining performance, stability, and handling qualities for simulated two- and four-propeller tilt wing aircraft [Ref. 9].

The program features options that the user selects from menus in a windows-oriented environment to acquire and alter data and perform various analyses. User selections specify the analysis simulations to be run, the geometry of the configuration, weights, and aerodynamic coefficients to be used. Ref. 10 is a User and Maintenance Manual which outlines procedures to be followed for utilization and modification of the TWANG computer code. The document presupposes a relatively high level of familiarization with tilt wing technology. The computer code is capable of providing the data and coefficients necessary for input into the NASA Ames VMS as part of a dynamic, real-time aircraft simulation. The three main outputs provided by the program are static trim/off trim calculations with resulting forces and moments, stability derivatives for programmed and geared flap control systems, and wind tunnel aerodynamic coefficients. Aircraft static trim (pitch system equilibrium) is measured by the convergence of aircraft pitch rate angular velocity and pitch rate angular acceleration, and wing angular velocity and angular acceleration towards a set threshold. The threshold for which the accelerations and velocities converge is 0 ± 0.0001 (deg/sec^2 or deg/sec, respectively). If convergence is not reached after 50 iterations, a figure representing the moment required to trim (balance) the wing-fuselage system forces and moments will be displayed in the outputs, discussed later. Convergence is accomplished within the computer code by taking the wing incidence angle, initial fuselage attitude, and final airspeed requested by the user, and deflecting the control surfaces and summing their effects upon the wing-fuselage system. Only longitudinal stability parameters are calculated. An internal data dictionary provides error checking of inputs and help messages prior to actual runs.

The TWANG program has gone through a number of refinements within the past year and is currently a (relatively) easily understood research tool. Sixteen different parameters are provided by which an extremely thorough analysis can be conducted in a matter of a few seconds. The 16 parameters comprising the Trim Summary Output are: airspeed, fuselage attitude (THETA), wing incidence, trailing edge flap deflection angle, trim status (VALID, FORCED, or ITERATION LIMIT EXCEEDED), horizontal tail incidence, longitudinal stick deflection (DCX), propeller blade angle of attack (at $0.7\bar{c}_{blade}$) (BETAPR), wing incidence reference angle (WIREF0), thrust output of propellers, magnitude of moment required to trim aircraft (AMTT), required horsepower at the given airspeed (REQ HPOWER), tail jet thrust moment produced (TMTJET), wing pivot moment produced (PIVMOM), effective angle of attack for the wing-fuselage system (ALFAE), and maximum equivalent angle of attack (ALFAEM). The TWANG FORTRAN declared variables are listed in parentheses. A few words of explanation concerning these output parameters are due. The trim status message is displayed as VALID if the wing and fuselage are each within the previously specified limits (approximately zero) for both angular velocity and angular acceleration before 50 iterations. The status of the simulation is listed as over the iteration limit (>iter) if the angular rates are not zero after 50 iterations and no control surface has reached its set deflection limit. If any of the controls (flaps or elevators) reaches their stops in the midst of trimming the aircraft for the desired airspeed and wing angle, a FORCED trim message will appear, along with a value of the moment required to trim the aircraft at the last iteration completed. This moment, designated AMTT, normally arises in a hover or low speed simulation, usually as a result of insufficient tail jet power available for that particular control configuration. The versatility of TWANG allows for custom user input files, output summary text files in Microsoft Word document format, and trim plots of the 16 different parameters in a format compatible for use with CricketGraph or KaleidaGraph plotting software. TWANG utilizes over 20 subroutines and is not presented herein due to its large size (in the neighborhood of 200 pages).

As V/STOL aircraft usually present wind tunnel researchers with problems due to wall interference effects [Ref. 2], validation of TWANG as an accurate prediction of tilt wing performance is an important event. Once validated, it can provide fast and inexpensive results during crucial beginning and intermediate design phases and predict performance prior to flight tests.

Hover flight was addressed as the starting point for all analysis using TWANG. During the initial simulations, the results from the output parameters indicated that the simulated CL-84 could achieve hovering flight with the present geometric and aerodynamic inputs. These results also showed that the longitudinal stick deflection usually reached the forward stick travel limit and the elevator deflection was at its maximum travel. The conclusion drawn was that the simulated aircraft had just enough pitch control to maintain a hover, but that there would be no margin for maneuvering longitudinally in this condition due to the fact that the controls were at the stops. Within the computer code, as in the CL-84 aircraft, the longitudinal stick deflection was directly linked to tail thrust control power at slow speeds [Ref. 7]. As more tail control power is needed to counteract a pitching wing-fuselage system, forward stick deflection was increased. The elevators on the CL-84, as well as within the code, were directly linked to longitudinal stick deflection (hence, also, to tail control power). Increasing the tail control power above that listed as the nominal value, 1.35 rad/sec^2 [Ref. 2], would not bring the stick and the elevator back to a desired neutral position. A sensitivity study which increased the maximum amount of tail jet power within the program was conducted. It showed that the effect of increasing the tail power available (to counter pitch moments) was to reduce the moment about the wing pivot, but did not appreciably change the stick position. As a consequence, the elevator remained in the fully or near fully deflected position during all hover simulations.

The TWANG program had to be modified to accommodate the CL-84 hover performance. This involved changing the Controls

Schedule and Sensitivity tables, both within the FORTRAN program and the TWANG windows environment. Two additional parameters, tail jet bias and tail jet moment bias, are now calculated and included as part of the output. Additionally, an extra column labelled Tail Jet Bias under the Controls Schedule and Sensitivity table [Fig. 18] was created. Tail jet bias is a number (lbf of thrust) which is extracted from its table during each iteration of the trim calculation and added to the force produced by the tail jet. This total force is used by the program when summing forces and moments about the aircraft pitch axis. Tail jet bias moment is the tail jet bias multiplied by the moment arm of the tail from the aircraft CG (25.76 ft). This parameter is also used when the program sums the forces and moments in pitch. These bias values adjust the longitudinal stick and elevator positions to neutral while in hover. This has the very desirable effect of enabling the full range of longitudinal control motion, while in hovering flight, for both the stick and the elevator.

The method for calculating the Tail Jet Bias table of values was achieved by Churchill and Nieusma in the following procedure. First, from the hover inputs, the range of longitudinal stick motion was constrained to ± 0.1 in. This compelled the code to calculate a forced trim point, and, more importantly, a moment needed to trim the aircraft, AMTT (ft-lbf). The aircraft was simulated from zero to 50 knots in increments of one knot, giving a moment for each increment of airspeed. These AMTT values were divided by the moment arm of 25.76 ft, and the resulting forces (lbs) were plotted against wing incidence (deg). Starting at 0° wing angle, the force calculated at each wing angle increment of 5° was taken from the plot [Fig. 11] and inserted into the newly added Tail Jet Bias table. The bias force eventually decreases to zero at approximately 45° wing incidence. At this point, the elevator should have sufficient authority to provide pitch control and no additional tail power from the tail jet bias table is needed.

After changing all the TWANG data arrays and all subroutines which called upon the Control Schedule and Sensitivity table, TWANG would not accept any input file after this modification. The source of error lies in the Macintosh windows environment associated with reading the input files. This problem is still under investigation and negated the use of the windows-style operating environment. As a substitute, Churchill then modified the TWANG program to produce test output files when run as a FORTRAN batch-type program. This format was used for all simulations and the results shown herein.

C. CL-84 INPUTS TO TWANG

As a first step towards familiarization by the writer with the TWANG computer code, the configuration and aerodynamic input files for the NASA four propeller simulation were loaded as inputs and attempts were made to duplicate some of the plots used in the pre-simulation documents. As several of these practice runs were successfully completed, CL-84 input files were created based on inputs from a variety of documents, including flight test reports [Ref. 6, 8], aircraft three-view drawings [Ref. 10] and weight and balance documents [Ref. 11]. As previously mentioned, the program was also altered to accommodate tail jet biases which allowed for neutral longitudinal control positions in a hover.

The following sections describe the TWANG operation from the windows environment.

1. SETUP

It must be noted that aerodynamic tables based on CL-84 wind tunnel data were not available, and that the aerodynamic tables used were extracted from a two-propeller configured tilt wing study by Boeing Vertol [Ref. 12]. For this reason, trends and results very similar in magnitude to that of flight test data have been analyzed with respect to possible known shortcomings in the procedure. The two most significant are the approximate aerodynamic coefficients and the simplified flowfield representation within the TWANG math model. After due consideration is given to these factors as sources of variation of the outcomes, results indicating close agreement between the simulations and test flights should be accepted as indicative of the TWANG computer code's accuracy in approximating tilt wing aircraft performance. Validation of TWANG as an acceptable predictor of performance may well speed additional research in this field, as well as provide valuable aircraft performance information. This information on flight regimes too risky or costly to evaluate experimentally would be especially valuable.

a. Job Setup (and Identification)

Job title, user, and several option command lines are available within the TWANG files to annotate simulations by the user for future reference. Notes such as flight conditions, aircraft configuration, flight regime, etc., were used. Fig. 8 is an example of the Job Setup menu. Three

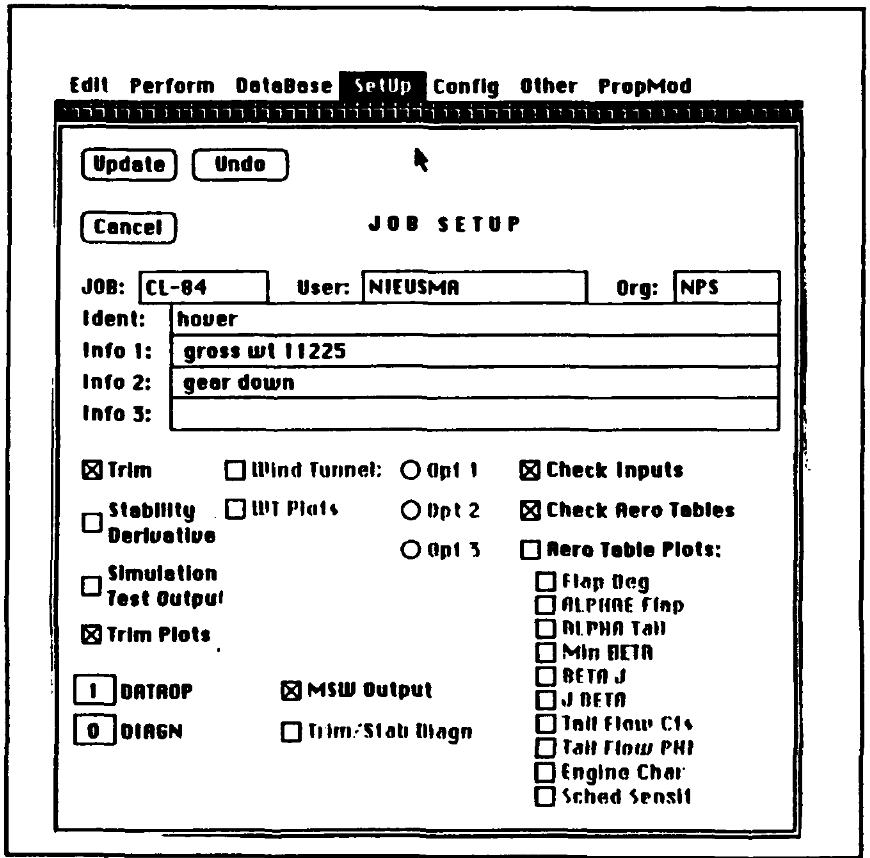


Figure 8 TWANG Job Setup Menu

simulation options are available: Trim and Stability, Wind Tunnel, and three data diagnostic options. Additional options which can be selected include an MS Word text output of the results, a format check of the configuration and aerodynamic tables, and aerodynamic plots.

b. Flight Conditions

Flight condition inputs were minimum airspeed, airspeed increment, number of airspeed increments, pressure altitude, temperature, axial load factor, normal load factor, rate of climb, propeller design tip speed, and landing gear

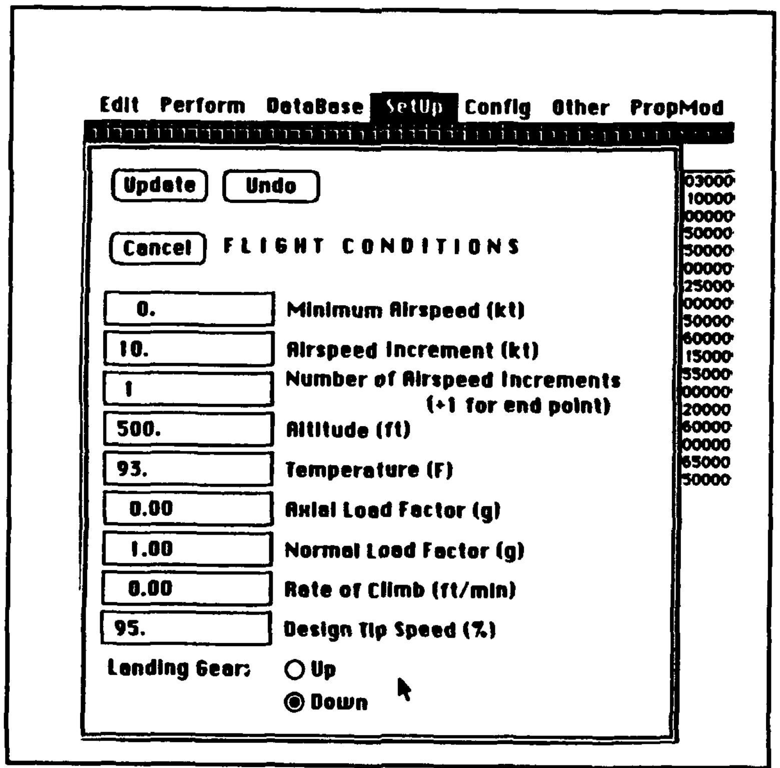


Figure 9 TWANG Flight Conditions Menu

position. Typical inputs for hover are shown in Fig. 9:

c. Flap/Tail Options

The first option is the type of trailing edge flap control schedule: discrete, programmed, or geared. Programmed and geared flap settings will change flap deflection as wing incidence is varied, to a maximum of 25° down. Up to five different discrete flap settings can be entered. The amount of programmed flap scheduled may be attenuated by selecting less than 100% of the flap deflection per flap setting. For example, entering 50% programmed flap [Fig. 10] will produce only half of deflection available at 100% deflection. The geared flap gain (15 degrees/degree) can also be changed for a similar effect for the geared flap system, if selected. The programmed flap schedule [Fig. 11 (a)] was provided in Ref. 6 and is displayed

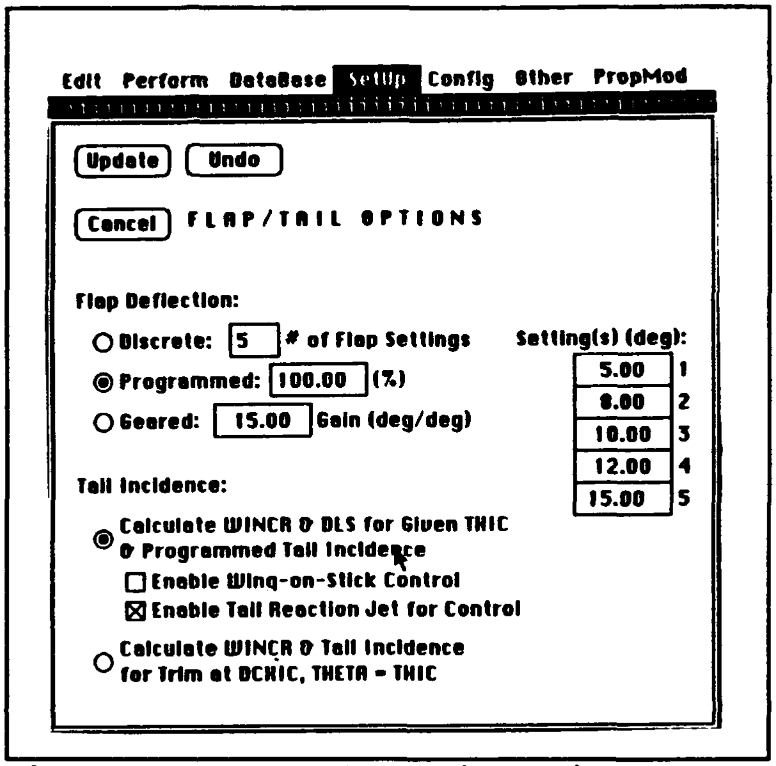


Figure 10 TWANG Flap/Tail Options Menu

as a function of main wing incidence (i_W) under the Configuration section (Controls Schedule and Sensitivity). The tail incidence (i_T) schedule varies with wing angle and is also located in the Controls Schedule and Sensitivity table. Fig. 11 (b) shows tail incidence versus wing incidence. The elevator is not scheduled according to wing incidence, but is proportional to the longitudinal stick displacement and is calculated within the program and displayed in the output.

Two options are available for a simulation run which involves varying the tail incidence calculations performed by TWANG. The first option is for TWANG to calculate wing incidence (WINCR) and longitudinal stick deflection (DLS) for a given fuselage angle-of-attack (THIC - THETA initial condition). This is the normally selected option if it is desired to keep the fuselage at a certain attitude (i.e., level with the horizon) and display the necessary wing angle and stick position to maintain that attitude as airspeed varies. Two control options under this analysis are to enable Wing-on-stick control and enable the tail reaction jet for pitch control. The Wing-on-stick mode of control (direct wing alteration through the movement of the stick) provides wing rate feedback as well as flap deflection for pitch control while hovering. Longitudinal control inputs rely on both wing angle and flap deflection feedback signals in this mode. The operation of the geared flap relies on the use of the flaps as servo tabs for controlling wing movement

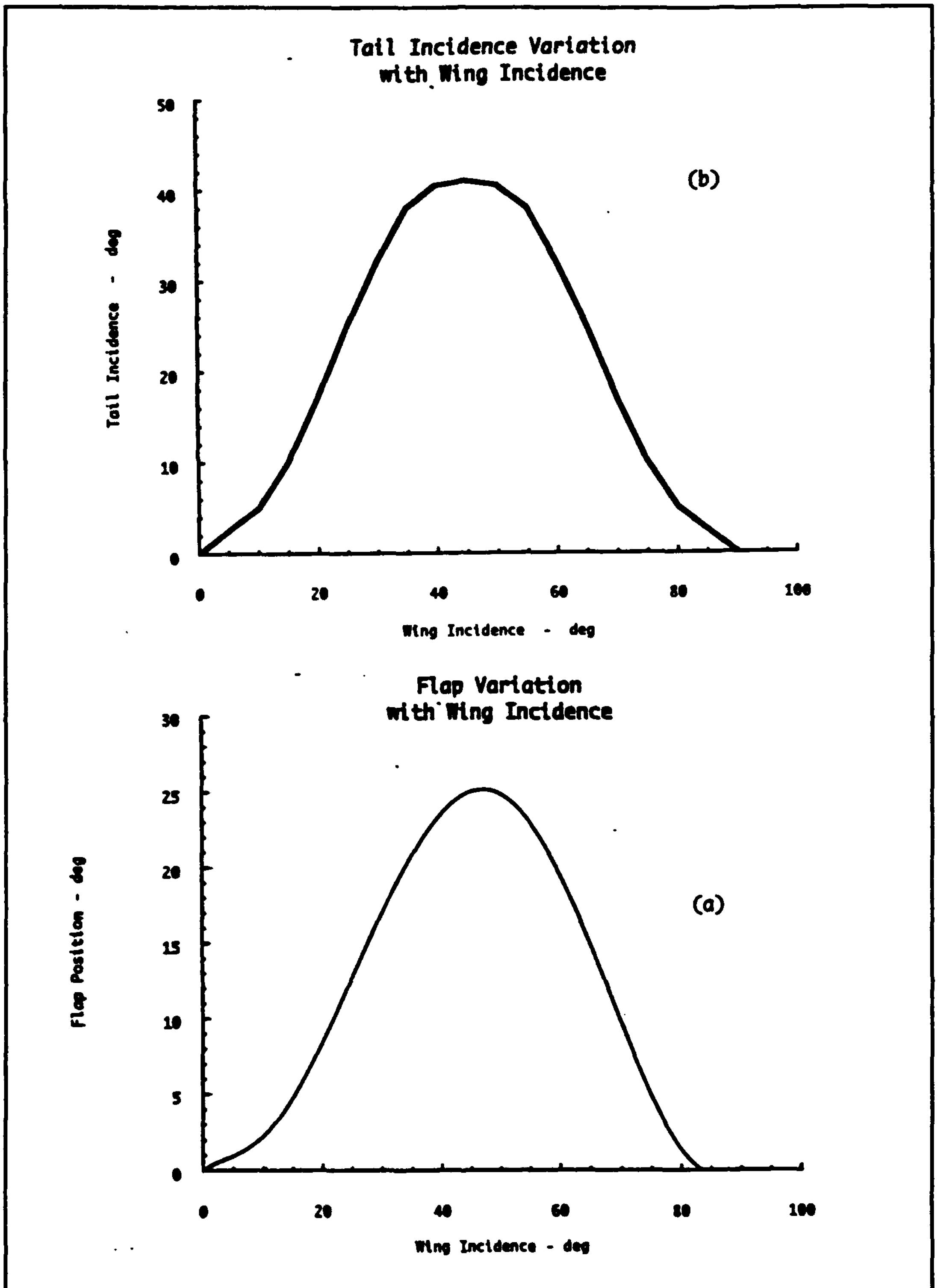


Figure 11 CL-84 Flap and Horizontal Tail Deflection vs Wing Angle [Ref. 6, 17]

while hovering. The Wing-on-stick mode was not used during any simulations, nor was the geared flap. A short explanation of their associated options is provided for completeness. The tail reaction jet is normally enabled for simulations with airspeeds of 120 kn or less. This is because the CL-84 disengages the tail rotors at a maximum speed of 125 KIAS. Problems in simulation can occur when the desired range of airspeeds falls about this 120 kn region, since the tail jet cannot be turned off in the middle of a simulation. TWANG reads the tail jet operation as either on or off for the entire simulation; as a result, extra power from the tail may influence the true position of the stick and the elevator. In addition, too much tail thrust can have a negative effect on pitch control. In order to diminish this possibility, the DRT tables are used [Fig. 18]. The DRT (the acronym is lost upon the originator) values are gains associated with the tail jet which start at zero for $i_w = 0°$, increasing to 1 at $i_w = 30°$. These gains have the effect of "washing out" the tail power at low wing incidences, where the tail control force is not needed. This is an attempt to simulate disengaging the tail rotors at speeds above 125 KIAS, which is a design feature of the CL-84.

The second tail incidence option analysis feature calls upon TWANG to calculate wing incidence and tail incidence at a given longitudinal stick deflection (DCXIC) and the initial fuselage attitude (THIC). This option was not used.

d. Power/Miscellaneous Options

Three types of simulations involving the calculation of power required are under power options [Fig. 12]. The first and most often used option requires TWANG to calculate the power required for a user-selected glideslope (GAMMA) and aircraft g-loadings in the x- and z-directions (NX,NZ). All simulations were conducted as straight and level flight paths. No simulations involving a rate of climb or descent were conducted. The aircraft loading was conventional for straight and level flight: one g in the z-direction (gravity), and zero g's in the x-direction (longitudinal). The second analysis feature calculates glideslope given power available

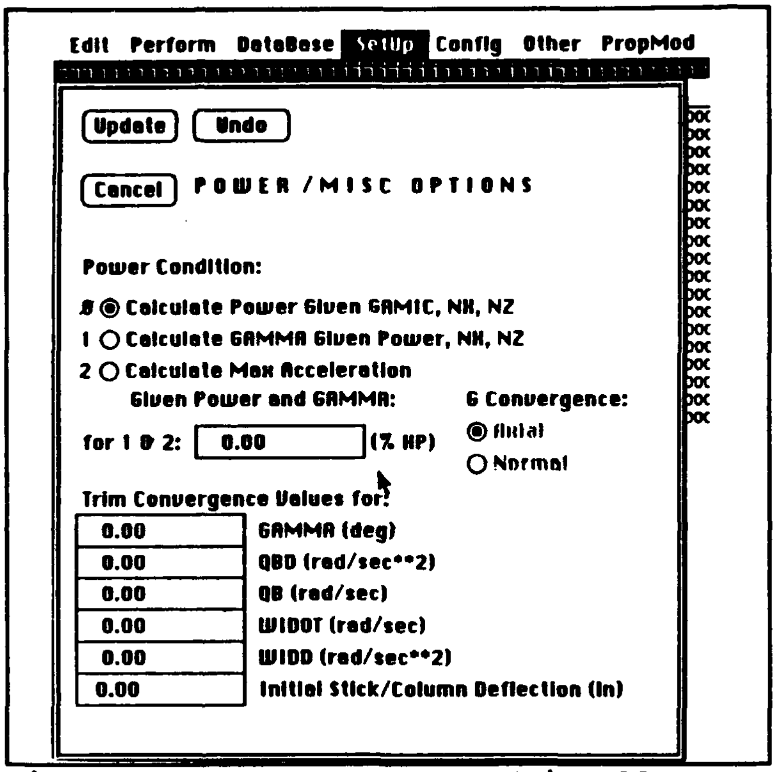


Figure 12 TWANG Power/Miscellaneous Options Menu

and g-loadings. The third analysis feature calculates the maximum accelerations when glideslope (deg) and power available (SHP) are provided. Selection of either of the last two options requires the user to select the percentage of horsepower available for the analysis, with less than 100% SHP available mimicking a humid day. The third option iterates either g-forces in the x-direction (axial) or in the z-direction (normal) until the user-provided power available and glideslope values are reached. When these two values are reached within a tolerance of four significant digits, the maximum acceleration (g-force) at this power and glideslope is calculated and listed in the output.

The second half of the menu contains the values about which TWANG will iterate when trimming the aircraft. These options are related to the values of glideslope, fuselage pitch rate and angular pitch acceleration, wing incidence rate and angular acceleration, and initial stick deflection desired for trim convergence. The value for each of these was set to zero for trim convergence, as shown in Fig. 12, with a threshold tolerance of 0.0001 for each parameter. Setting these to zero means that the fuselage and wing will not be accelerating when the aircraft is considered to be trimmed and stable. Glideslope is changed by choosing a figure less than or greater than zero in the GAMMA selection box.

e. Fuselage Attitude Options

This is one of the more important and useful options for simulating the aircraft fuselage angle of attack (THETA). The program will calculate either wing incidence or fuselage attitude for trimmed flight. Suppose the user wishes to know at what wing incidence the aircraft will be trimmed (i.e., at zero pitch rate velocity and acceleration and wing angular velocity and acceleration) when the fuselage attitude is not allowed to vary more than ± 2°. The wing incidence option is chosen for this type of simulation. The user also selects the initial wing incidence to begin its calculations of the required i_w for ± 2° fuselage pitch. A value of i_w = 80° was used throughout the simulations, an angle taken from studies of the NASA Ames four propeller simulations. The other option, Attitude for Trim, allows the user to select up to five discrete wing

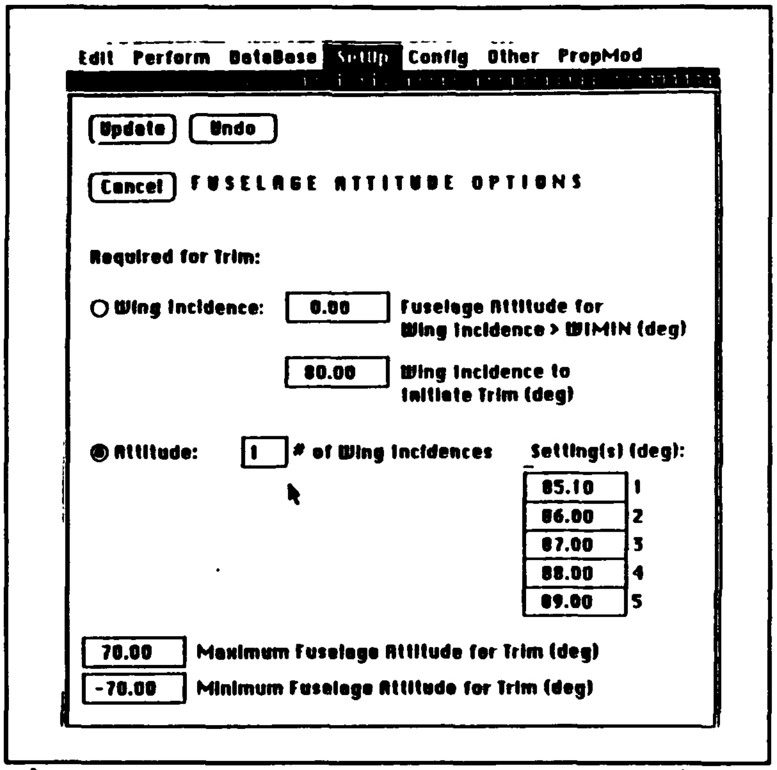


Figure 13 TWANG Fuselage Attitude Options menu

angles with up to five settings each. The program calculates the attitude for the trim condition at each wing incidence. The attitude required for trim option was used extensively in the present analysis when comparing simulation results to test flight data. Most of the test flight data was recorded while operating at a single wing incidence. By similarly running a simulation at a single wing incidence, data variation due to different wing angles was not introduced. The user also selects the maximum and minimum fuselage angles allowed for the aircraft to be considered trimmed. These values were chosen as ± 70° in order to provide a large range of fuselage motion for calculation of a stable attitude during the simulation. This was done with the understanding that 70° of nose up or nose down attitude would be extremely uncomfortable in an actual aircraft, and that an aircraft travelling through such extreme angles of attack enroute to a stable attitude would have totally unacceptable handling qualities. Fig. 13 is a display of the Fuselage Attitude Options menu.

2. CONFIGURATION

a. Wing items

All inputs to the Wing Items menu were taken from the aircraft three view from Ref. 10. Wing span is not presently used by the program in any calculation and is not needed as an input. Chord extension ratio and maximum chord extension ratio numbers were not available, and values of 1.25

and 1.25, respectively, were used as inputs. These values were taken from the previous NASA Ames four-propeller simulation. To analyze the effects of an arbitrary selection, a sensitivity study was conducted for each parameter. The range of ratios used in each case varied from 1.00 to 1.50, in increments of 0.05. In each case airspeed was varied from 0 to 150 knots (maximum flap deployment speed). The effects on stick displacement, thrust, and power required were analyzed. The only noted effects were variations of 3-4 horsepower at the extremes of 0 and 140 knots from the range of 1.00 to 1.50 for the case of each ratio. As this effect is vary small in comparison with the figure of 1500 hp in a hover, the ratios of 1.25 and 1.25 were considered acceptable. Fig. 14 shows the wing inputs for the CL-84 aircraft.

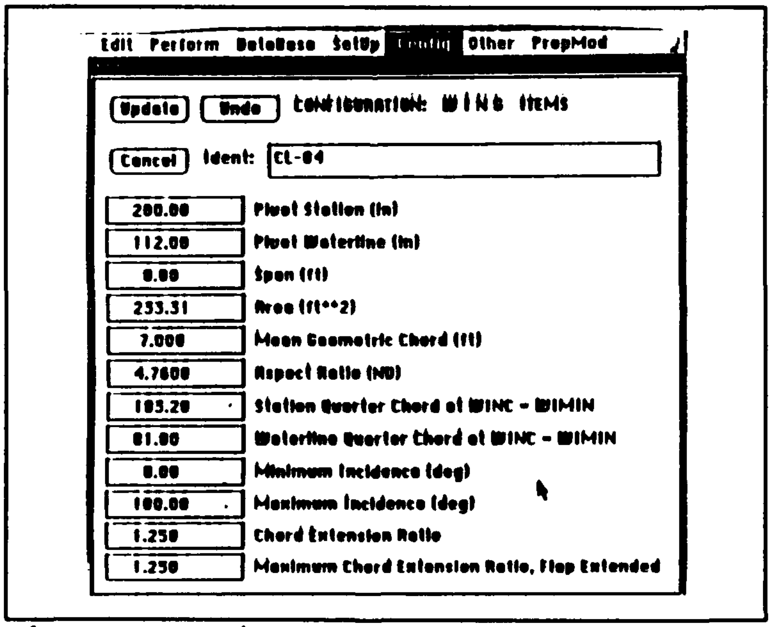


Figure 14 Wing Items

b. Propeller Items

All inputs for propeller items were taken from Ref. 8. Solidity was calculated assuming a rectangular blade planform [Ref. 13]Z. Fig. 15 shows the CL-84 propeller inputs used.

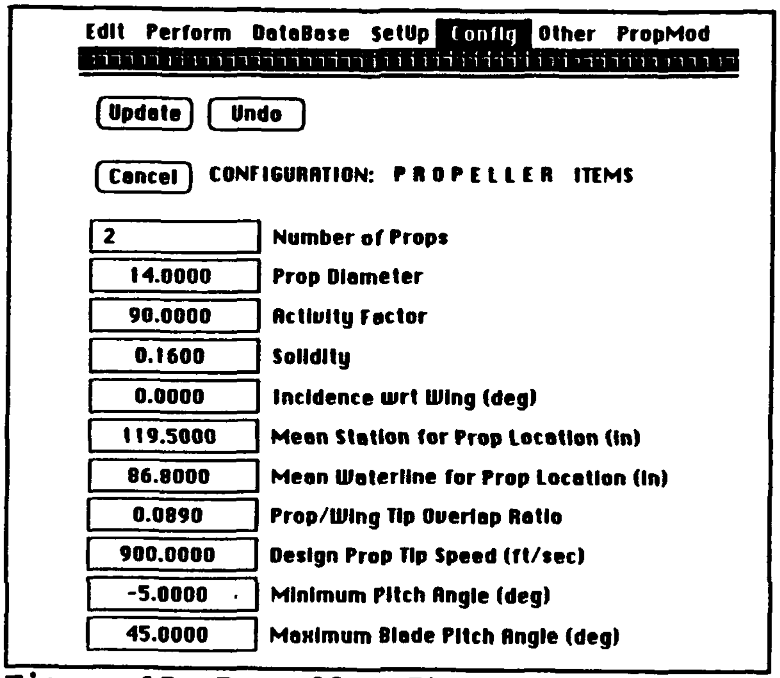


Figure 15 Propeller Items

c. Tail Items

All geometric data used in this menu was taken from the aircraft three view [Ref. 10]. The tail jet hover power value, taken from Ref. 7 as the power output of the CL-84 tail device, is $\pm$ 1.35 rad/sec^2. This value is significantly higher than the 0.6 rad/sec^2 used for the previous NASA Ames four-propeller simulation. Of greater significance is that the CL-84 aircraft is much smaller than the four- propeller aircraft. The ultimate goal of reduction or elimination of tail thrust for pitch control is more difficult to realize with the CL-84. The large moments about the CL-84 wing pivot must be countered by the smaller control surfaces of the two-propeller aircraft if tail thrust is not used. Also, a significant percentage of hover power available (8%) comes from the tail propellers of the CL-84, a factor which could have an important impact on performance calculations [Ref. 7]. Fig. 16 shows the tail inputs.

d. Flap/Engine/Stick/Cockpit/Axle/Strut Items

Of this conglomeration of inputs, only minimum and maximum flap deflection, engine rated power, and the longitudinal stick deflection limits are used by TWANG for simulation. All other inputs are utilized by the Vertical Motion Simulator and are not necessary for the calculations of aircraft performance during the simulation. The inputs used are taken from Ref. 8 and shown in Fig. 17.

e. Miscellaneous Items

These inputs represent various aircraft geometry values for the VMS and are not used in any TWANG program trim calculations.

f. Engine Characteristics

This table is used by the TWANG program as a cross check for the maximum horsepower available during a trim iteration. If horsepower required for a simulation airspeed exceeds horsepower available (1500 SHP), a logic statement uses the smaller of the two values in the calculations. The given flat-rated output of each engine was used (1500 SHP) [Ref. 7].

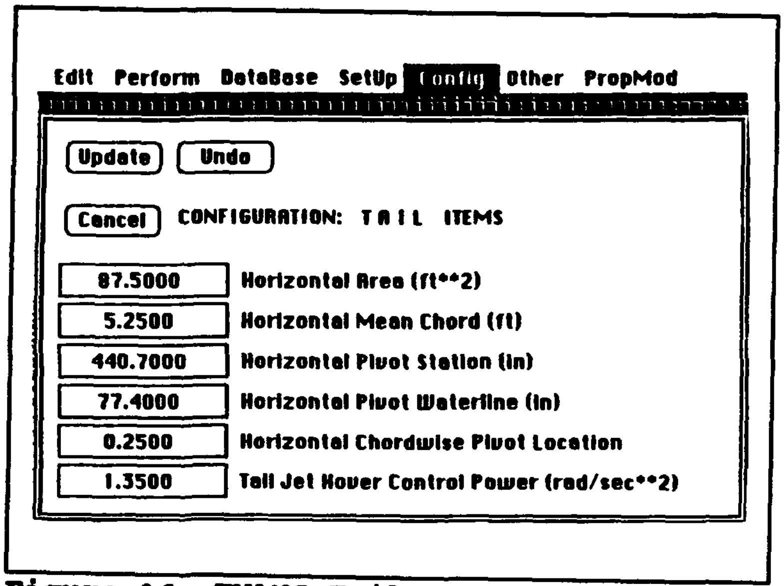


Figure 16 TWANG Tail Items menu

<u>**g. Control Schedule and Sensitivity**</u>

This table is extensively utilized by TWANG to extract the various control schedules and their variation with wing incidence. The Pivot Moment column (PivMom) is a bias table used for the four-propeller model, similar to the Tail Jet Bias table for the CL-84 simulation. All values were set to zero and thus do not affect any of TWANG's simulations. The flap schedule was taken from Ref. 6 and is shown in Fig. 11. The tail incidence schedule was taken from the CL-84 Aircraft Operating Instructions [Ref. 14]. The values for each 5° wing increment were extracted off the graph of the tail schedule [Fig. 11]. The DRT table is a table of gains used in conjunction with the tail control jet. At small wing angles the tail jet power is reduced. As previously discussed, this table is necessary because the tail jet power is either on or off during a trim iteration and,

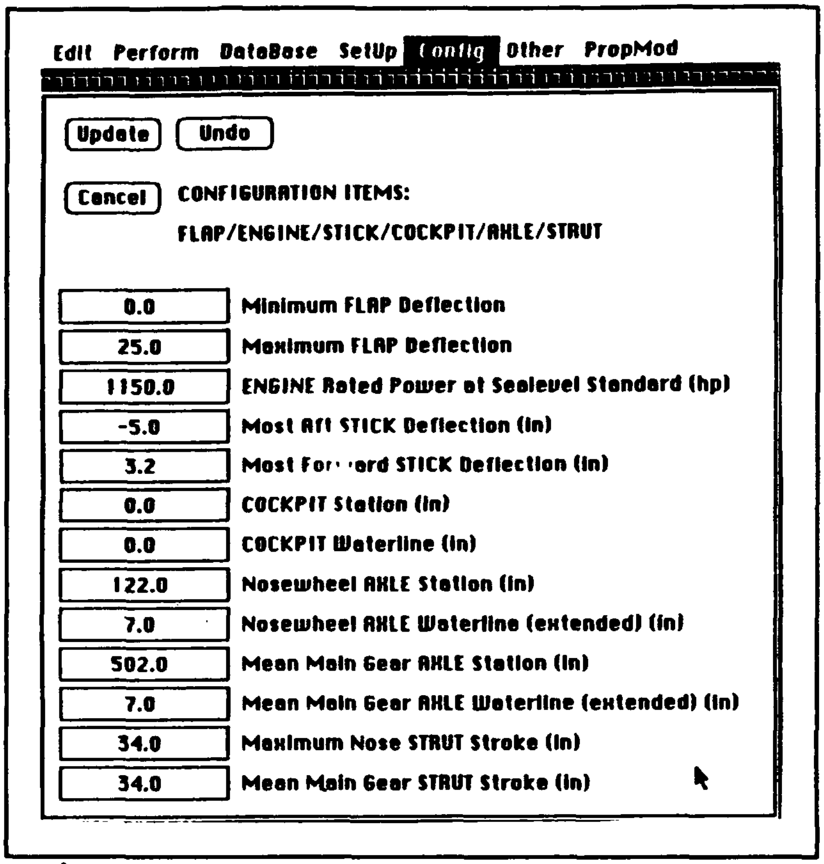


Figure 17 TWANG Flap/Engine/Stick/Cockpit/Axle/PropMod menu

at the present, TWANG has no capability for automatic disengagement and engagement at certain specified airspeeds. For the CL-84 aircraft the tail rotors were turned off at approximately 120 knots. The Wing-on-Stick column is also a table of gains for the Wing-on-Stick control configuration for the Geared Flap mode and is not used during programmed flap analyses. On the far left of Fig. 18 there is room for an additional column. Within the controls schedule data array internal to the program there exists additional space as well. Changes made by Churchill and Nieusma to utilize this space for a tail jet bias table were unsuccessful, due to an interface problem between the TWANG program and the Macintosh computer menu inputs. This interface problem was unresolved (and remains so), leading to the use of a batch type input to the program for all analytical results.

Edit Perform DataBase SetUp Config Other PropMod

Update Undo CONTROL SCHEDULE/SENSITIVITY

Cancel Ident: CONTROL SCHEDULING & SENSITIVITY,9/9

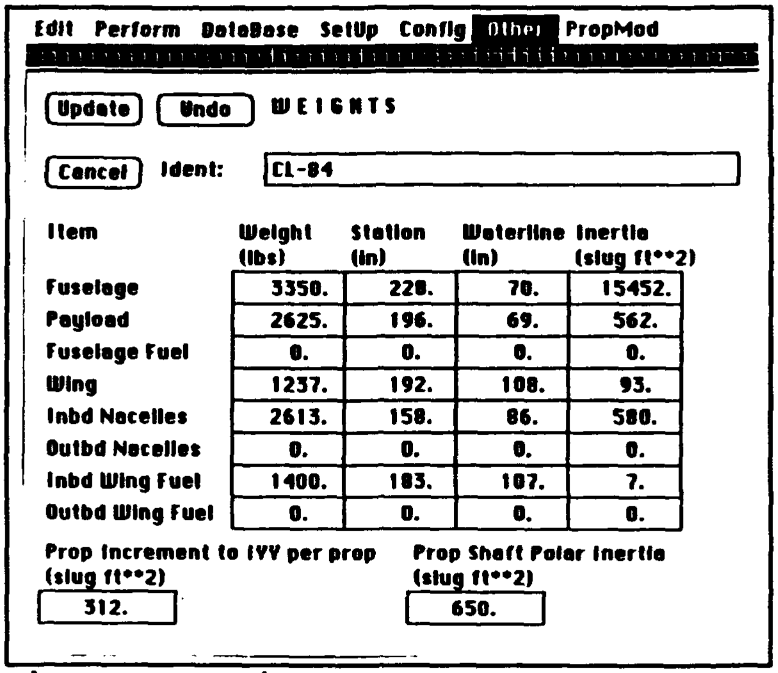
	WREF (deg)	PlvMom (ft lb)	Flap (deg)	Tail Inc (deg)	DRT	Wing on Stick
1	0.	0.	0.	0.0	0.000	0.000
2	5.	0.	1.	7.1	0.217	-0.434
3	10.	0.	2.	14.0	0.434	-0.868
4	15.	0.	5.	20.5	0.560	-1.120
5	20.	0.	8.	26.4	0.783	-1.560
6	25.	0.	13.	31.4	1.000	-2.000
7	30.	0.	17.	35.5	1.000	-2.008
8	35.	0.	21.	38.5	1.000	-2.000
9	40.	0.	24.	40.3	1.000	-2.000
10	45.	0.	25.	41.0	1.000	-2.000
11	50.	0.	24.	40.3	1.000	-2.000
12	55.	0.	23.	38.5	1.000	-2.000
13	60.	0.	20.	35.5	1.000	-2.000
14	65.	0.	15.	31.4	1.000	-2.000
15	70.	0.	10.	26.4	1.000	-2.000
16	75.	0.	5.	20.5	1.000	-2.000
17	80.	0.	1.	14.0	1.000	-2.000
18	85.	0.	0.	0.0	1.000	-2.000
19	90.	0.	0.	-1.0	1.000	-2.000
20	100.	0.	0.	-1.0	1.000	-2.000

Figure 18 TWANG Control Schedule and Sensitivity menu

3. WEIGHTS

a. Weights

All weight information is taken from the weight and balance data in Ref. 11. Weight and inertia data is found for several different weights at all aircraft stations. In this manner, the aircraft center of gravity and gross weight may be altered to closely match flight test conditions. Propeller shaft moment of inertia is not currently used in any



Item	Weight (lbs)	Station (in)	Waterline (in)	Inertia (slug ft**2)
Fuselage	3350.	228.	78.	15452.
Payload	2625.	196.	69.	562.
Fuselage Fuel	0.	0.	0.	0.
Wing	1237.	192.	108.	93.
Inbd Nacelles	2613.	158.	86.	580.
Outbd Nacelles	0.	0.	0.	0.
Inbd Wing Fuel	1400.	183.	107.	7.
Outbd Wing Fuel	0.	0.	0.	0.

Prop Increment to IYY per prop (slug ft**2): 312.

Prop Shaft Polar Inertia (slug ft**2): 650.

Figure 19 Weight Items

calculation and is not necessary as an input within the code. Fig. 19 shows a typical weight distribution for a gross weight of 11225 lb and CG of 38.4% MAC:

b. Aerodynamic Coefficients

Inputs to this menu [Fig.20] were not available during this study. As an approximation to the CL-84 coefficients, inputs from the four-propeller model were initially installed and, later, compared to data derived from DATCOM methods for a comparably sized twin turboprop aircraft [Ref. 15]. Although discussions with NASA Ames tilt wing engineers indicate that these inputs are reasonable estimates, they are only approximations and are a potential source of discrepancy when comparing CL-84 simulation data with flight test results.

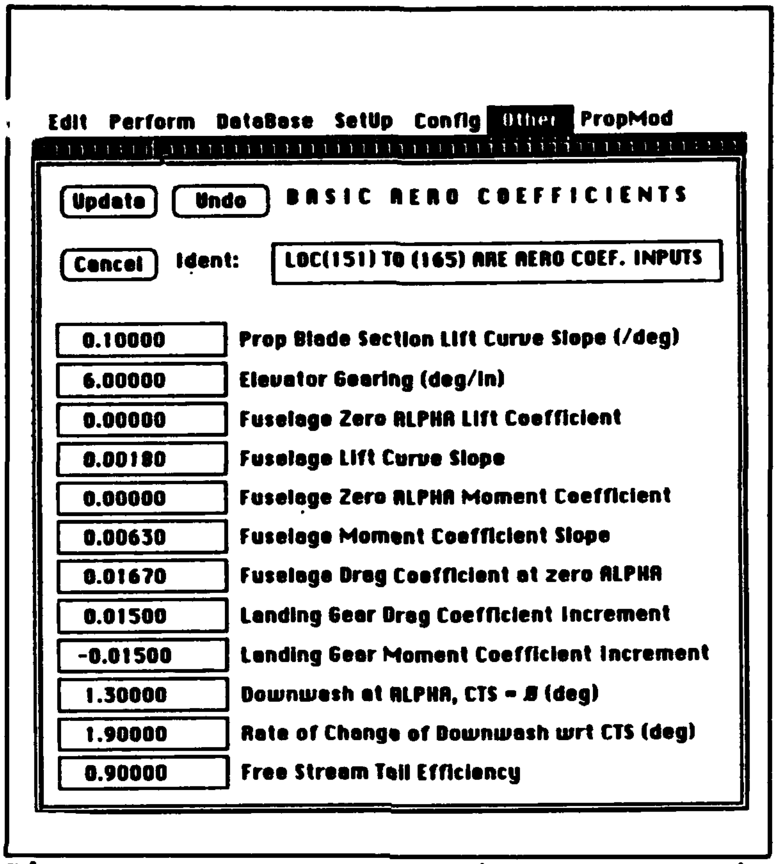


Figure 20 TWANG Basic Aerodynamic Coefficients menu

D. TLTWNG!! MODIFICATION OF TWANG

As previously mentioned, Twang was modified in order to accommodate the CL-84 aircraft, involving adding bias terms read by the program at higher wing incidences (> 40°). The difficulties in coaxing TWANG and its various subroutines to read the modified data arrays were not solved at the time of this writing, and the program was modified by Churchill to accept batch-type input files. Appendix B contains an example input file with comments added for faster modification when changing the input conditions. The first four digits represent the first of five array locations for the input information, with a maximum of five 14-space locations available per line. The fifth digit is an optional number which displays the maximum number of input values located on the line, with a maximum of five. Appendix B also contains a Tilt Wing Trim Inputs document, which gives the array location of each input. This batch run program mode was renamed TLTWNG!! and was used for all simulations described in this report. Following the configuration document are three sample pages of detailed text output, available from the user's choice of the terminal screen, printer, or a text file. An additional output is a file named TRIMPLOT which can be imported to either KaleidaGraph or CricketGraph graphing software. This file contains the resulting values of the various tilt wing parameters such as fuselage attitude (THETA), longitudinal stick position (DCX), flap deflection, etc., for the type of analysis chosen. This type of output allows for rapid graphical form comparison of many different calculated parameters. The comparisons of flight test data to simulation data were constructed in this manner.

RESULTS AND ANALYSIS

The most difficult area of vertical flight analysis is that of the hovering flight regime. This is due to lack of accurate estimations of velocity and pressure in the flow field, caused by problems in obtaining precise measurements of these parameters in a three-dimensional, turbulent, circulating body of atmosphere. As the TWANG math model does not take into account circulation or ground effects, the actual test results may differ from simulated results in part due to these effects. Additionally, the tail reaction jet in the math model is an idealized force producing jet thrust upon which wing and tail downwash have no effect within the code. These aerodynamic effects become greater, in a three-dimensional sense, in hovering flight than in normal freestream cruise.

All simulation plots have a box describing ^Xxe simulation conditions and flight test conditions, if different. All simulations were run with the aircraft out of ground effect and at a nominal propeller rpm of 95% of maximum [Ref. 7]. The tail jet power is on for all TWANG simulations, except as noted for $i_w = 0°$. The CL-84 tail rotors were disengaged by 120 KIAS, as previously noted.

In reference to the longitudinal stick gradient, aircraft are required to have a positive longitudinal stick gradient in

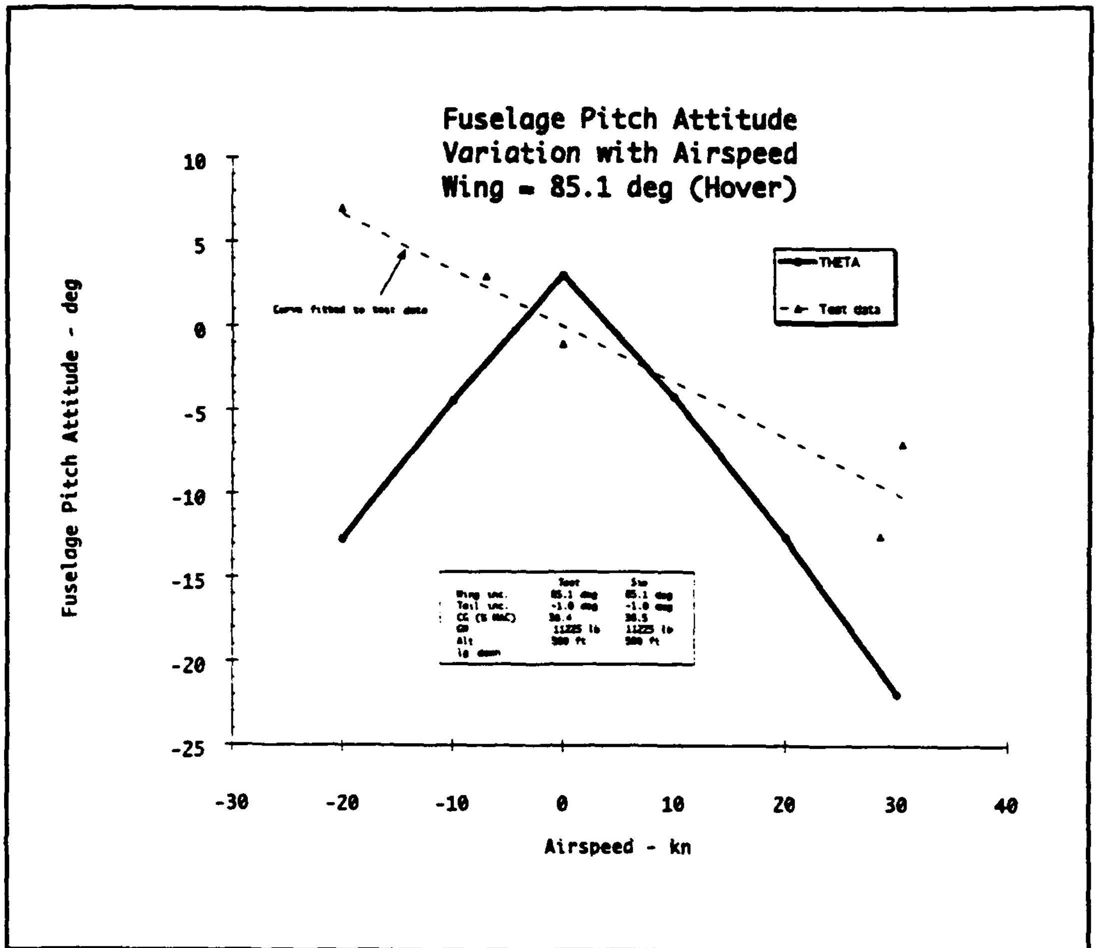


Figure 21 Fuselage Attitude $i_w = 85.1°$

order to obtain FAA airworthiness certification. This means that as the stick is moved forward, the aircraft nose must point down. Stick gradient for modern rotorcraft controls may allow a neutral stick gradient. At the time in the 1960's when the CL-84 was being tested, the positive stick gradient requirement was in place, as it was towards this requirement that the CL-84 was designed [Ref. 16].

A. WING INCIDENCE = 85.1°

Fig. 21 shows the fuselage attitude at a fixed wing angle of 85.1°. Pitch attitude predicted in rearward flight is substantially different than that of the flight test results. With flap deflection and tail incidence being identical for the comparison, two likely factors for this discrepancy are: 1) Dissimilar aerodynamic coefficients, and 2) Real effects of a 3-D flowfield about the aircraft. The second factor is particularly relevant with respect to the effects upon the CL-84's pitch control tail rotors. There is no effect upon the program's tail reaction jet. Recirculation in the vicinity of the tail rotors would have the effect of reducing the power produced by the rotors. A tail jet unhindered in this manner could explain the nose-low attitude in rearward flight, which is predicted by the program. Once in slow forward flight (0-30 knots), the fuselage is again predicted to be nose down, similar to the actual attitudes but more pronounced. Again, aerodynamic effects are the likely cause of discrepancy. With a fixed wing attitude which is nearly vertical, 20 - 30 knots is likely to be the maximum forward speed attainable. The aerodynamics of the flowfield in this flight regime are extremely difficult to predict. Two sensitivity studies were conducted to examine possible sources of variation within the fuselage attitude results. In the first study, tail control power was varied from 1.00 to 1.90

rad/sec^2, in increments of 0.05. The normal maximum value is 1.35 rad/sec^2. From this attempt to estimate the effects of varying control power upon pitch attitude, results indicated that pitch attitude was not changed for the entire range of tail power values. In the event that the calculated tail jet bias force was too large, a second sensitivity study was conducted. For this study, the bias force of 910 lb, corresponding to i_w = 85.0° [Fig. 18], was changed first to 510 lb, then to 110 lb. As previously mentioned, the Tail Jet Bias table was added to reduce the amount of forward stick present during the hover analysis in the original TWANG program. Taking away most of that added tail bias force would bring the stick forward once again while hovering. The results showed that the pitch attitude did not change with variation in the Tail Jet Bias.

As other sources of variation, such as tail and flap position, match or nearly match test flight conditions, the source of difference in the hover flight regime between TLTWNG!! simulation and test flight data is attributable to the aerodynamic tables used internally within the computer code. Of particular importance are the wing downwash tables, which are only approximated data, as previously mentioned. Also noteworthy is the fact that the tail rotors of the CL-84 aircraft provide a significant amount of lift in a hover. As a consequence, the impact of the tail thrust coefficient due to tail rotor blade angle-of-attack, dT/dα, has significant effect upon the CL-84 fuselage attitude in the hover flight regime which is not present in the simulation [Ref. 17].

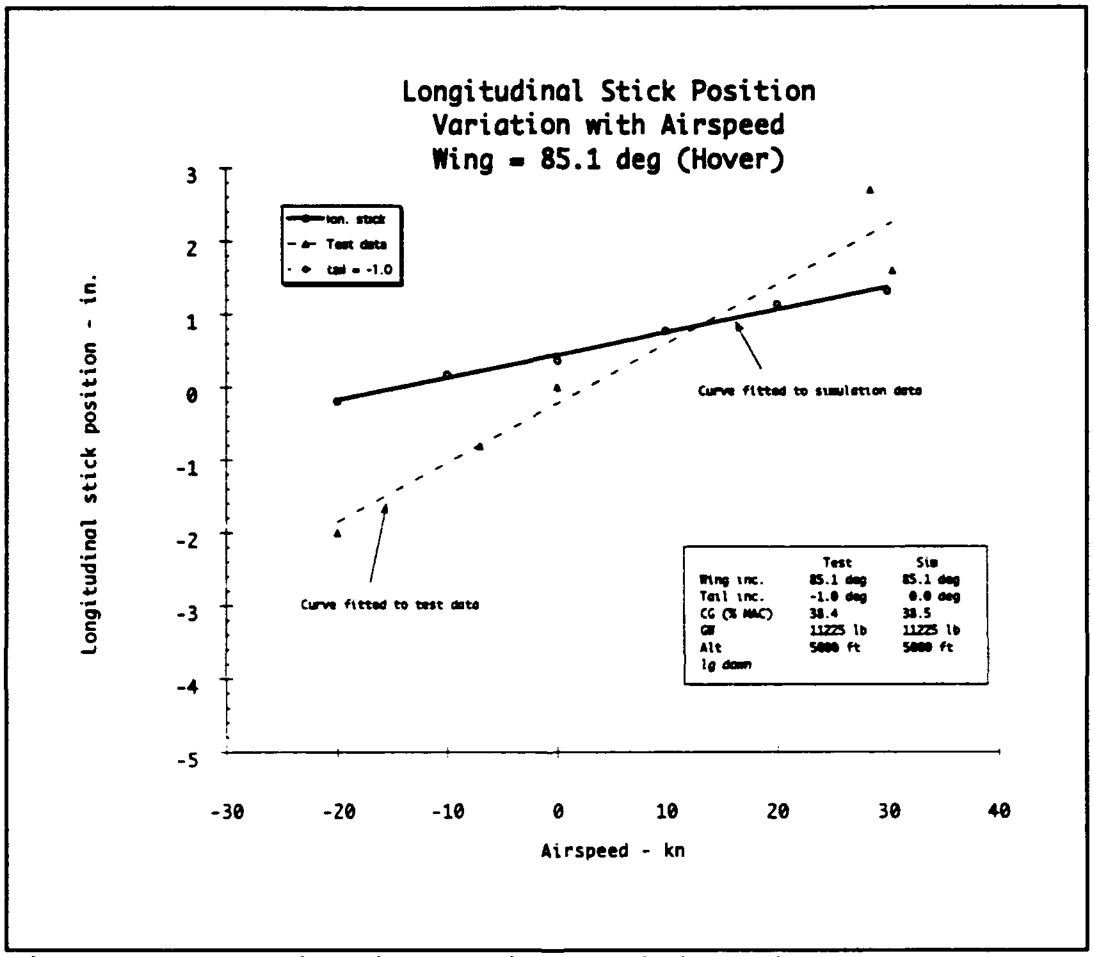


Figure 22 Longitudinal Stick Position $i_w = 85.1°$

Fig. 22 shows the corresponding prediction of longitudinal stick deflection. The desired result of a positive stick gradient is predicted, with the simulation stick gradient higher than that measured in flight. The results are shown against the full range of longitudinal stick motion, 3 inches forward to 5 inches aft.

Fig. 23 is the elevator position for $i_w = 85.1°$. It shows a higher amount of elevator deflection than that during flight testing. Elevator position , as mentioned, is calculated within the program as a gain (elevator gearing) multiplied by longitudinal stick position. This implies that elevator deflection (down elevator being positive) is increased in proportion to stick displacement within the computer code.

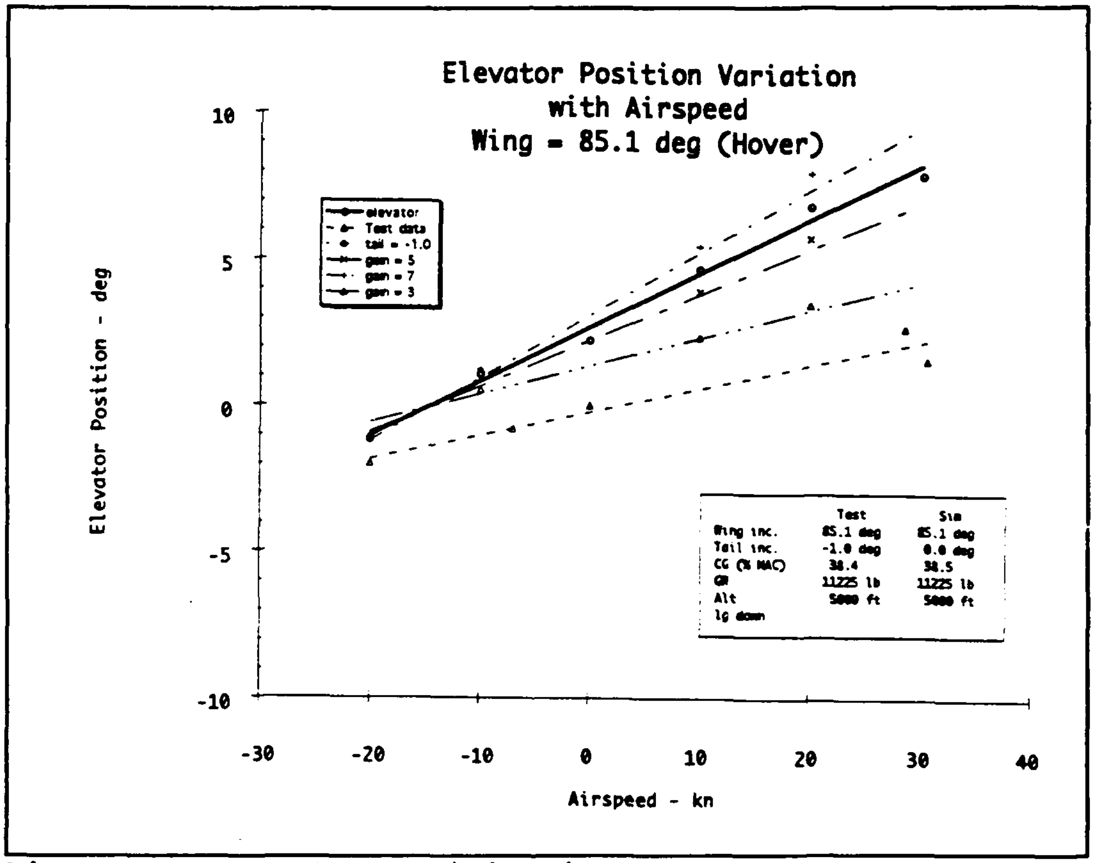


Figure 23 Elevator Position $i_w = 85.1°$

The slope of the curve in Fig. 23 indicates that the elevator gain may be incorrect. With no CL-84 gain information available, an elevator gearing of 6°/in. was used based on the NASA Ames four-propeller tilt wing VMS simulation. The last three plots on Fig. 23 are graphs of different elevator gearing (7°/in., 5°/in., 3°/in.). The slope of the TLTWNG!! simulation at a gain of 3°/in. is closer to the test flight elevator slope. The vertical displacement between these two parallel slopes is adjusted by changing the rigging of the elevator linkage on the aircraft. This would place the simulation data and test flight data on top of each other. A new elevator gearing of 3°/in. did not change the simulation pitch data, however. Furthermore, it also did not change the simulation pitch data for any of the other wing angles analyzed. The new gearing did change the longitudinal stick position slightly for each wing incidence, but the effects were varied. For some wing angles, the stick deflection was farther from the test flight data. For the other wing angles it was slightly closer. There was no recognizable trend in the simulation stick deflection as the elevator gearing was changed from 6°/in. to 3°/in. for the range of wing angles simulated.

B. WING INCIDENCE = 41.5°

This is configuration that would typically be used in STOL operations. Fig. 24 shows pitch variation with airspeed for

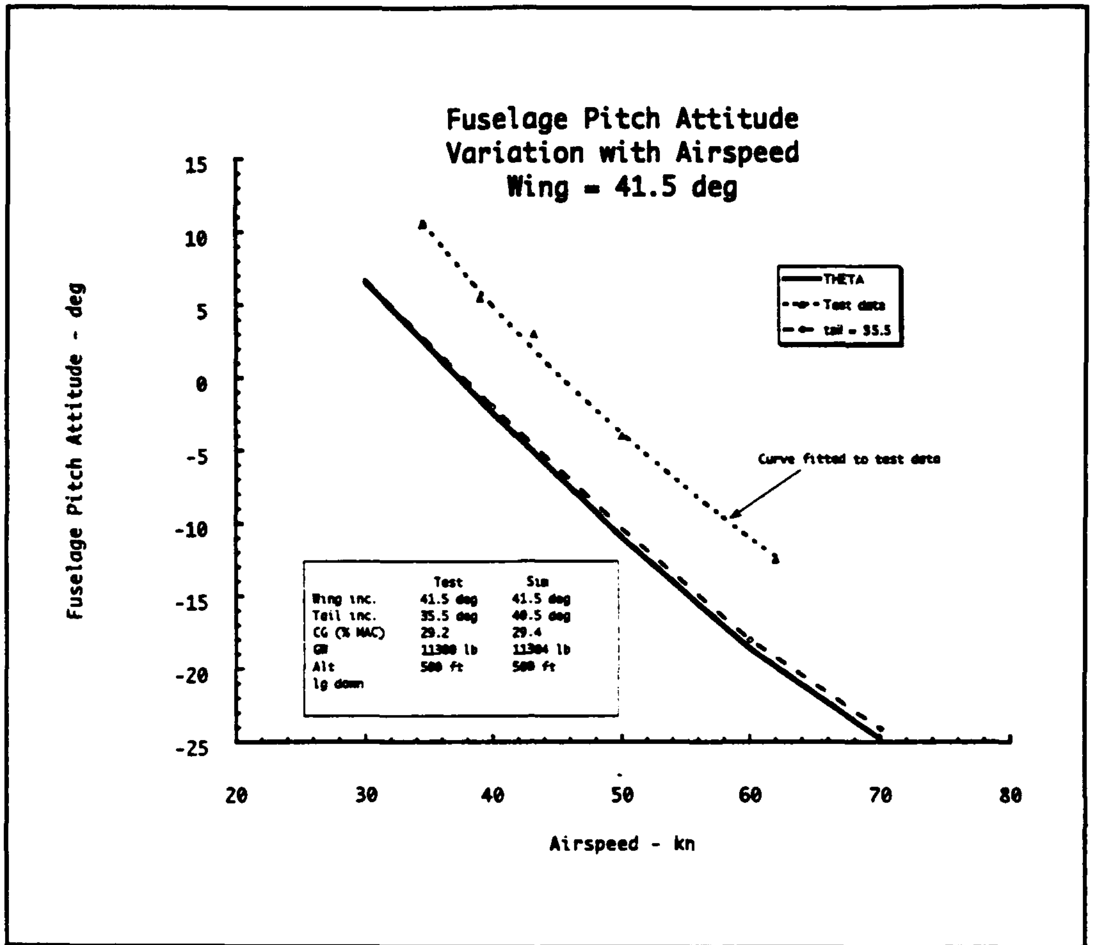


Figure 24 Fuselage Pitch Attitude $i_w = 41.5°$

this wing incidence. Although the slopes of the simulation data and the test flight data are nearly identical, the simulation data predicts a pitch attitude on the average of an additional seven to eight deg. nose down. The conclusion drawn is that the dynamic variation of pitch attitude with airspeed is very accurately predicted by TLTWNG!!, but that the aerodynamic coefficients used in the simulation are not accurately modelled. This hypothesis can be supported from the simulation pitch variation that was calculated when the tail incidence was matched to the flight test condition (35.5°). This is depicted in Fig. 24 by the graph of the parameter in the legend labelled tail = 35.5. The angle of incidence of the horizontal tail no longer becomes a source of variation. Of the two main sources of discrepancy, mentioned previously, 3-D flow effects should be discredited as the cause of difference by the simulation data and the test flight data. This is because of the nearly identical slopes of the two plots. Real flowfield effects would affect the fuselage pitch differently at different airspeeds. This does not appear to be the case at this wing incidence.

Fig. 25 presents the stick position variation with airspeed. Initially, at speeds of 30 - 50 knots, a negative stick gradient is predicted for the simulation and a positive stick gradient observed in flight. Beyond 60 knots, the simulation shows the tendency of a slightly positive stick gradient. At a wing angle of 41.5°, the operative range of airspeeds for aerodynamic efficiency are above 60 knots, while speeds less than 40 knots represent flight near the maximum lift capacity of the wing [Ref. 17], hence, near the stall region for this wing. The most likely cause of the dissimilar stick gradients in Fig. 25 is the higher tail control power needed from the CL-84 tail rotors near the stall boundary. As airspeed increases, and simulation tail control power required decreases, the simulation stick position will move forward, as shown in Fig. 25.

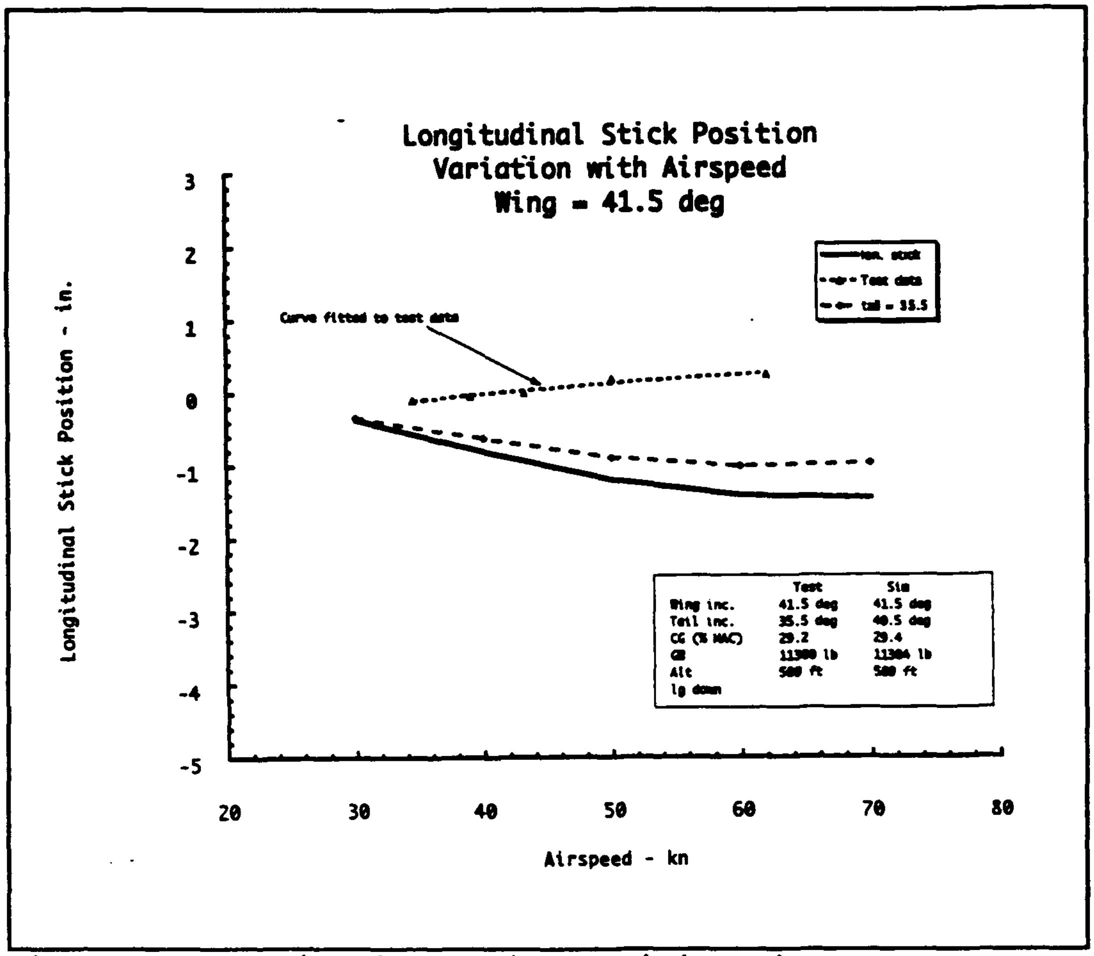


Figure 25 Longitudinal Stick Position $i_w = 41.5°$

A second simulation was run with the horizontal tail angles matched between the simulation and the test flight conditions at 35.5°. There is improved agreement with this new tail angle. The stick gradient appears to be less negative at airspeeds less than 50 knots and is very close to the test flight stick gradient at airspeeds above 60 knots. The displacement difference of approximately one inch between simulation and test flight plots could be handled by a flight controls rigging change to match initial stick positions. The most important point is the similar stick behavior within the operative range of speeds (60 - 80 knots).

Elevator position at i_w = 41.5° [Fig. 26] for the simulation data is a near mirror image of the stick behavior at this wing angle. Fig. 26 shows the effect of changing the simulation tail angle to match that of the CL-84 test flight condition (35.5°). The agreement with the test flight data is

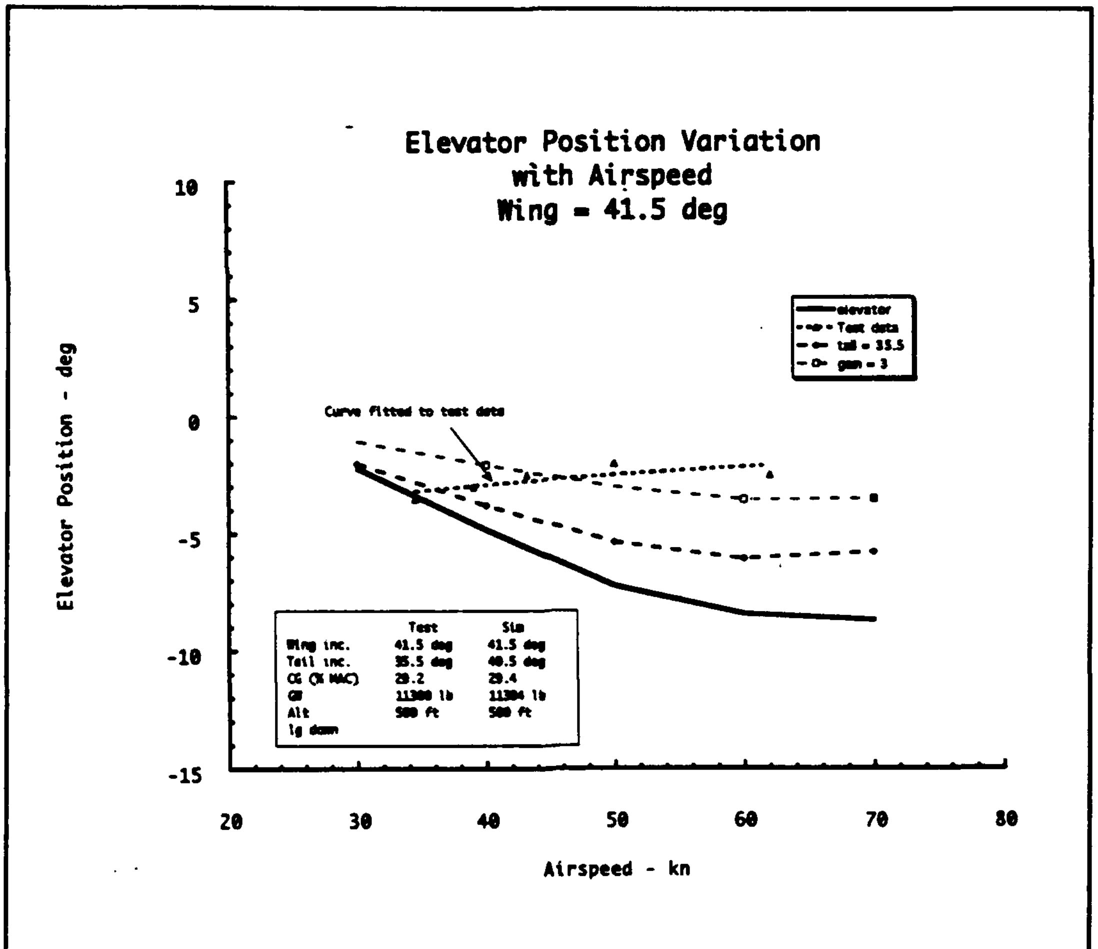


Figure 26 Elevator Position i_w = 41.5°

much closer. Again, flight near the stall region for this wing angle shows the elevator variation with airspeed to be changing in an opposite manner to that of the test flight variation with airspeed. Also, again, the slopes of the simulation and test data are nearly identical in the operative region above 60 knots. The last plot of Fig. 26 shows the effects of changing the elevator gain from 6°/in. to 3°/in. The average elevator position is now close to that of the test flight data, but the slope appears to be not quite as good as an elevator gearing of 6°/in.

C. WING INCIDENCE = 28.6°

This wing angle would be encountered normally only briefly, while transitioning from V/STOL wing angles to aerodynamic flight, or vice-versa. Airspeed ranges in the 40 - 50 knot range are representative of the $C_{L_{max}}$ value for this tilt angle. Fig. 27 shows that the fuselage pitch data from a first simulation nearly within the scatter of the observed flight test data and their slopes nearly identical. This indicates a good approximation of the CL-84 by the simulation for this flight regime. A second simulation with identical horizontal tail angles between the simulation and test flight conditions (23.5°) demonstrates a very similar slope, but with slightly greater nose up attitude, on the average. It appears that differences between the actual CL-84 aerodynamic coefficients and the simulation coefficients worked in

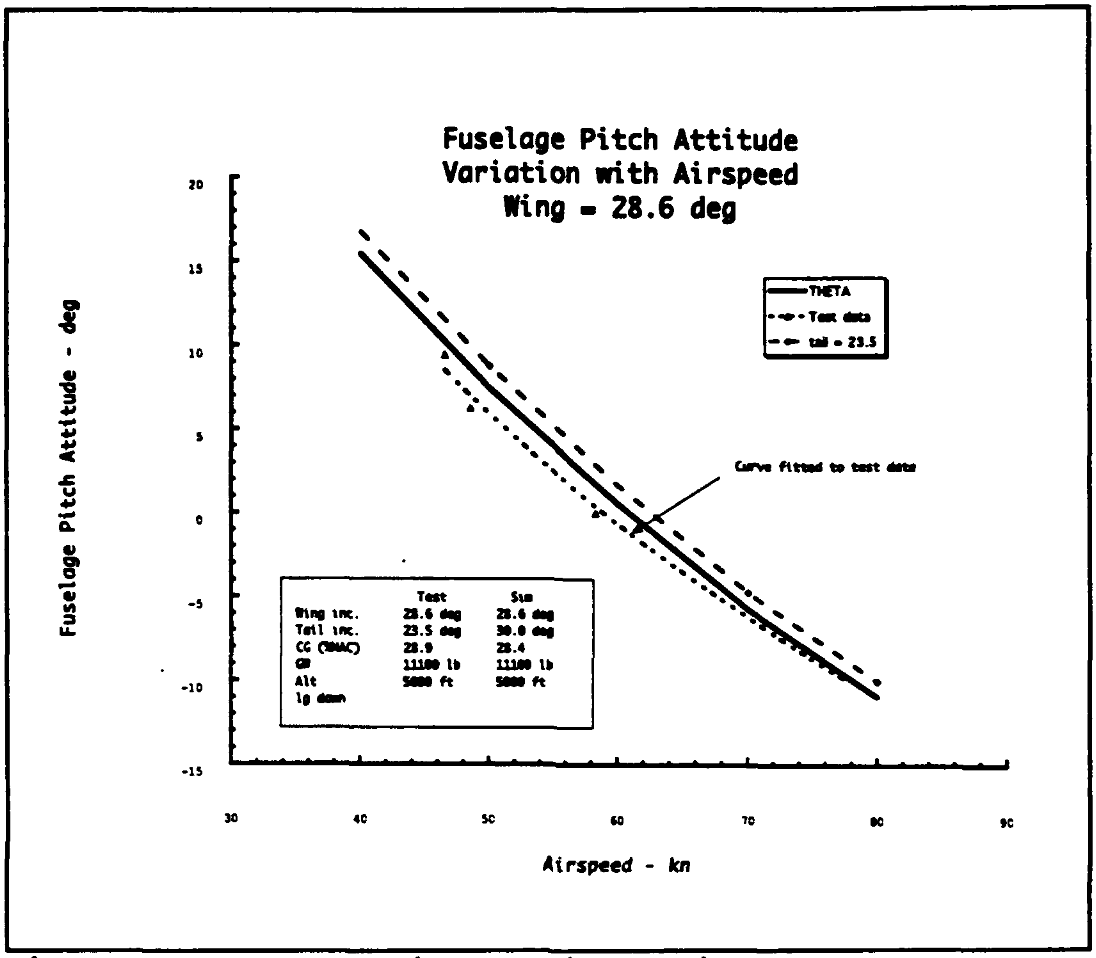


Figure 27 Fuselage Pitch Attitude $i_w = 28.6°$

conjunction with the 6.5° difference in tail incidence to neutralize (or at least lessen) their error contribution. Aside from this, agreement between the data is quite good.

Fig. 28 displays the results of stick position variation with airspeed for a wing angle of 28.6° over the total range of stick movement (3 in. forward to 5 in. aft). A fitted curve of the test data indicates a negative stick gradient. Since this was not a design characteristic of the CL-84, this data may be in error. Two simulations exhibit a slightly

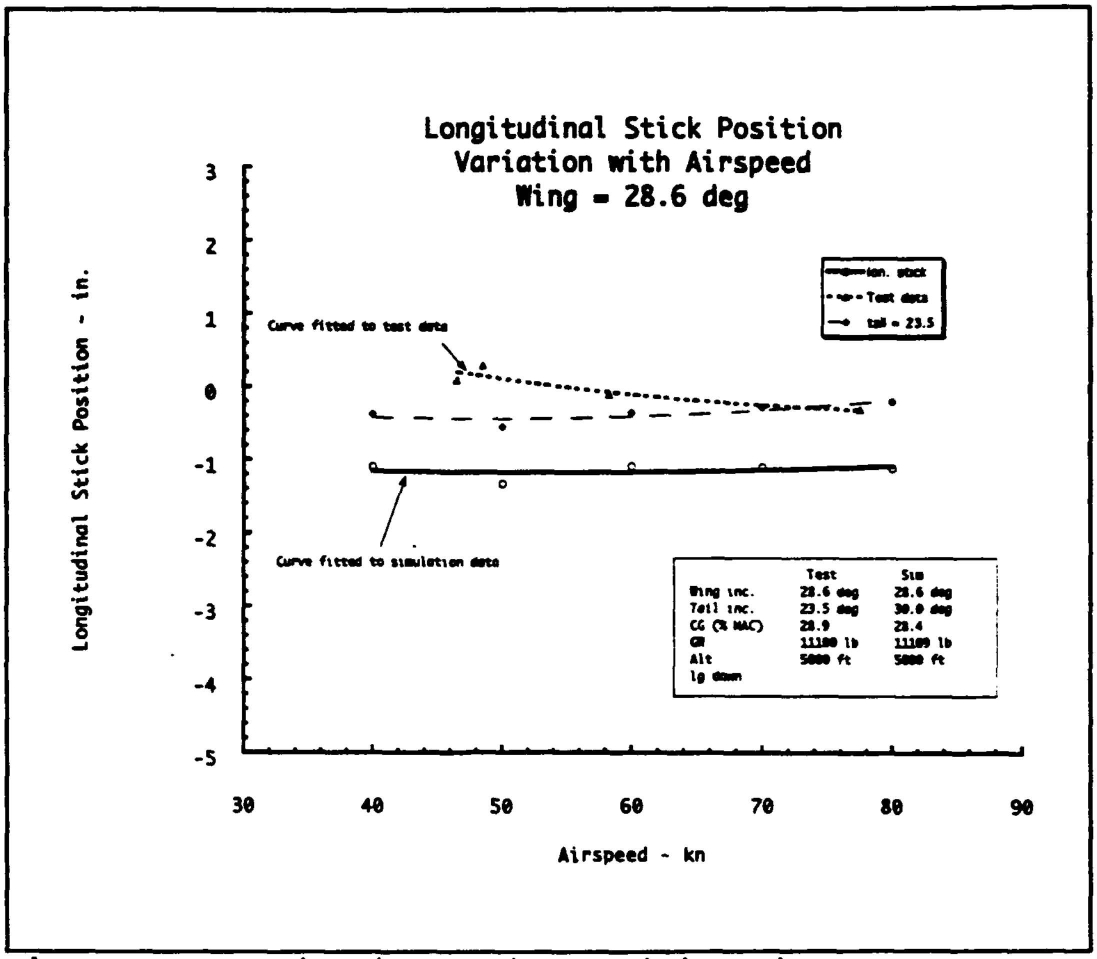


Figure 28 Longitudinal Stick Position $i_w = 28.6°$

positive stick gradient for these flight conditions. The second simulation, where the tail incidence is matched to the test flight tail incidence of 23.5°, demonstrates close agreement with the observed test flight data. This is due to less tail power required for trim at the new tail angle of 23.5°.

At this wing angle, there is a large difference in tail angles between simulation and flight test data. The effect of changing the simulation parameters to reflect the test flight

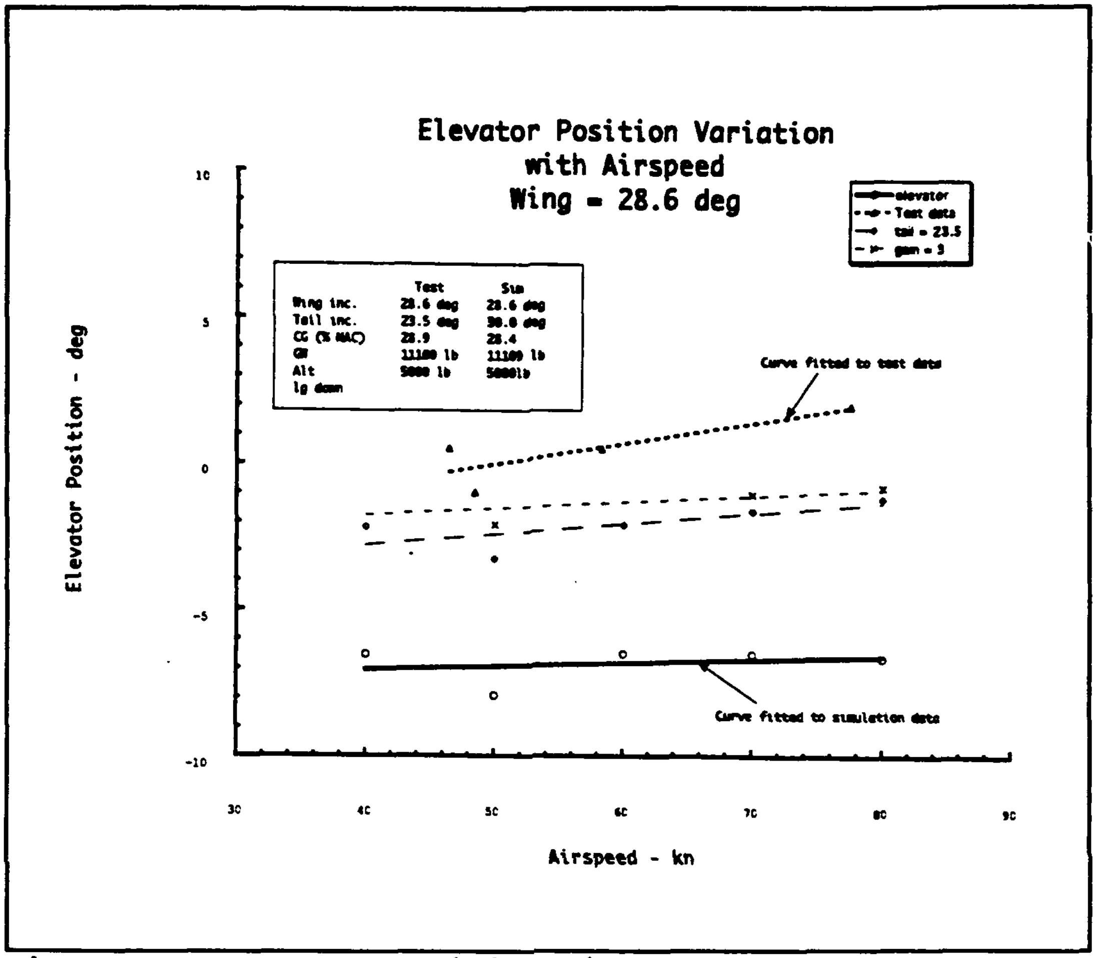


Figure 29 Elevator Position $i_w = 28.6°$

conditions more accurately is demonstrated in Fig. 29. The difference in elevator position between simulation and test flight data is reduced from eight degrees to three degrees up elevator, and the variation with airspeed is closer in slope to the flight test data than the data from the first simulation. The difference in the amount of up elevator carried by the CL-84 aircraft between the simulated data and test flight data is most likely the result of the higher fuselage attitude of the simulation data. An explanation offered is that the higher fuselage attitude requires more up elevator to remain at this angle. This difference in simulation data and flight data ,again, may be due to a combination of differences in actual and simulation aerodynamic coefficients.

D. WING INCIDENCE = 14.0°

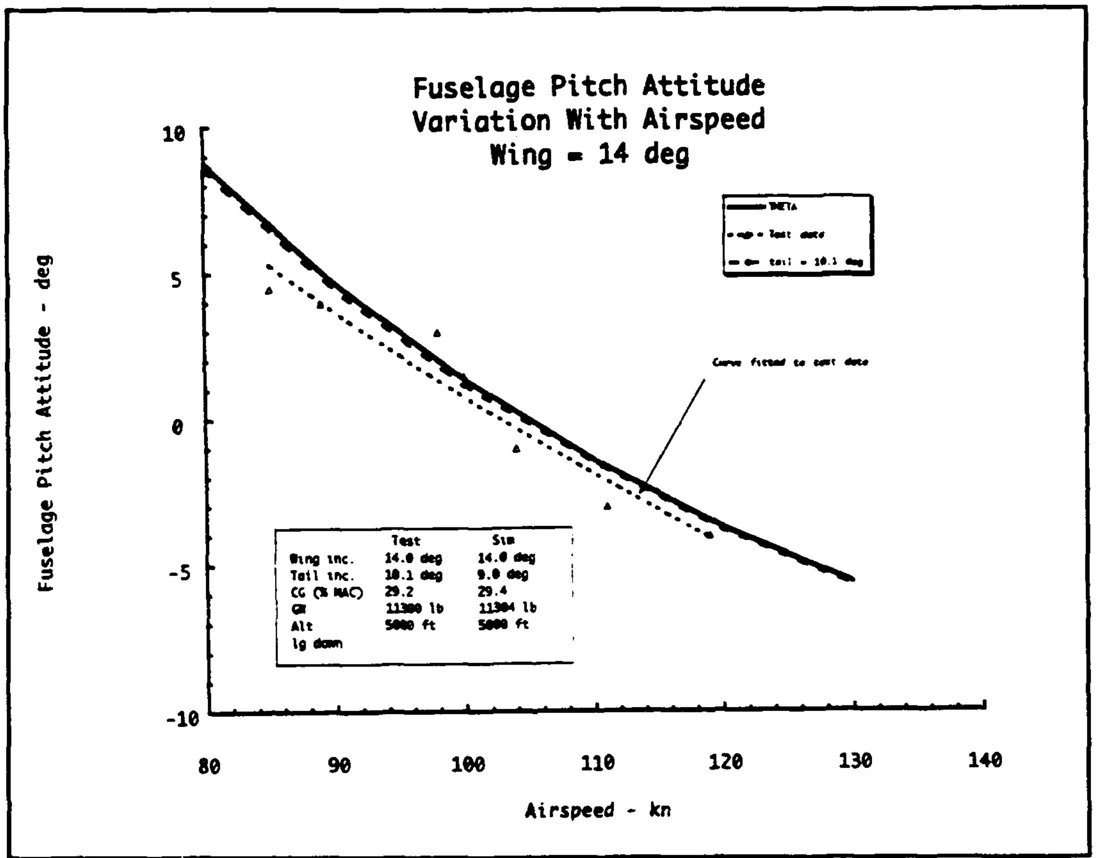


Figure 30 Fuselage Pitch Variation i_w = 14.0°

At this wing incidence, the CL-84 flight performance is characterized by its aerodynamic lift behavior more than its deflected slipstream traits. The three-dimensional flow effects become closer to two-dimensional as the tail control surfaces encounter freestream airflow more and circulation effects on the tail rotors less. The tail rotors are disengaged and stowed above 125 KIAS. Internally, TLTWNG!! has no capacity for turning off the tail reaction jet in mid-simulation. Fig. 31 shows this consequence for the stick position at this tilt angle. The change in fuselage pitch [Fig. 30] with airspeed is almost exactly matched to that of the test flight data over the operative airspeed range of 100 - 120 knots. It is, in fact, within the scatter of the observed test flight data. Some slight divergence between graphs is expected in the range of airspeeds from 80 - 90 knots, where the wing is operating near C_{Lmax} for this wing angle.

Fig. 31 readily shows the effect of an operating tail jet in the simulation past the tail rotor shutdown airspeed of 125 KIAS for the CL-84. From the DRT table in Fig. 18, the tail jet gain at $i_w = 14°$ is 0.74, or 74% of the normal amount of thrust it produces. Even with this reduction, in the range of airspeeds above 100 knots, the simulation stick position continues forward in Fig. 31, while the test flight stick position begins to level out. This is due to an operating tail jet within the simulation which is still nearly three-quarters as effective as it would be in a hover regime. This is obviously not the case where the CL-84 flight test data is involved. A second simulation with the exact tail angle as the flight test conditions places the stick position data on

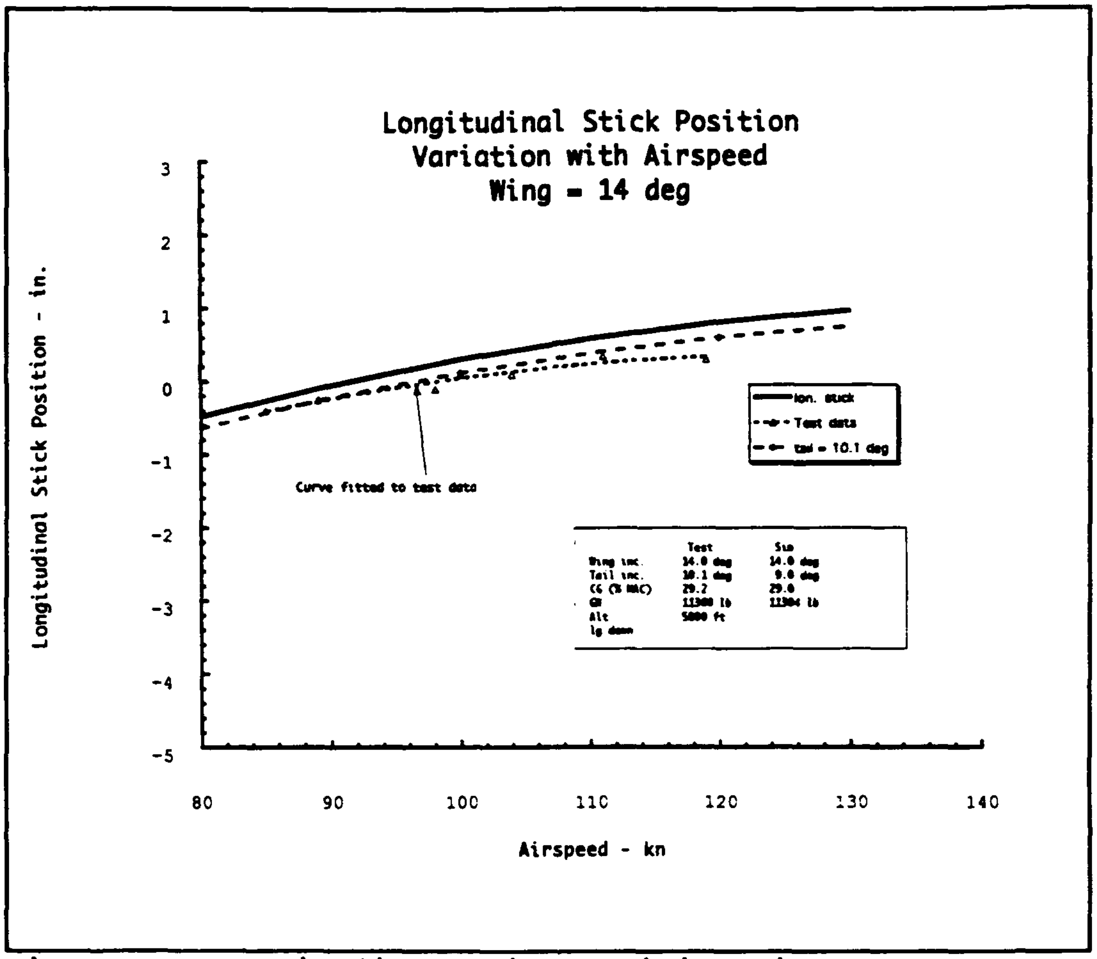


Figure 31 Longitudinal Stick Position $i_w = 14.0°$

top of the test flight results for excellent agreement.

An interesting phenomenon is exhibited in Fig. 32. Although the predicted fuselage attitude and stick position are in close accord with test flight results, the predicted elevator deflection is five degrees higher than that observed from the test flight data. A second simulation, with the tail incidence moved from 9.1° to 10.0°, shows an increase in elevator deflection of about one degree up elevator. This should be expected, as the aerodynamic effects of these two

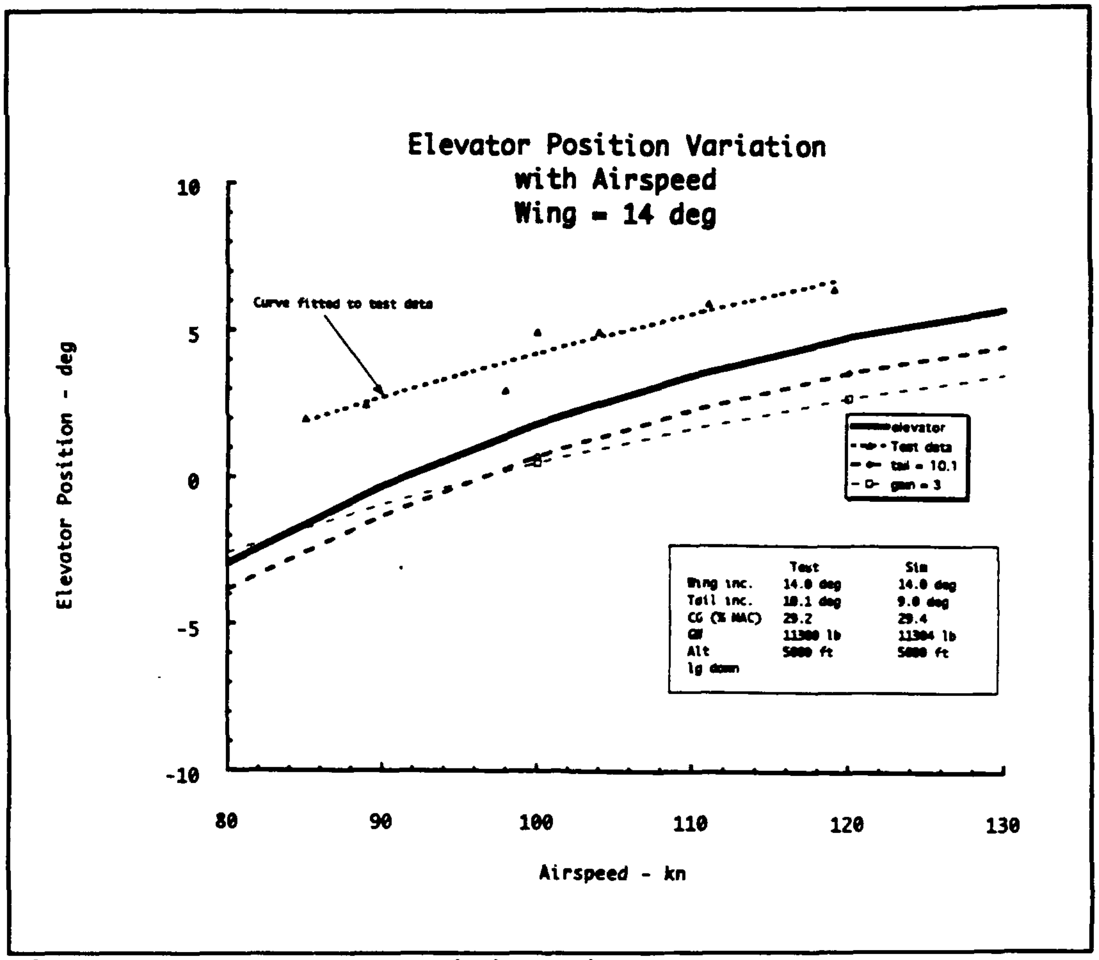


Figure 32 Elevator Position $i_w = 14.0°$

horizontal-tail-and-elevator combinations each yield an equivalent tail chord. The vertical displacement of the data of Fig. 32 are somewhat surprising in light of the excellent harmony between fuselage and stick simulation data and test flight data. The likely explanation lies with the extra degree of nose down, on the average, present in the simulation data. At airspeeds above 90 knots, the difference in aerodynamic coefficients, particularly pitching moment, most likely causes the elevator to deflect the extra three degrees up (on the average) in an attempt to raise the aircraft nose, or at least to prevent any further nose down attitudes. An important point is that the slopes of the simulation data and test flight data are practically identical, demonstrating close approximation to the CL-84 aircraft.

E. WING INCIDENCE = 0° (CRUISE FLIGHT)

For the range of airspeeds in this simulation, the tail jet was deactivated, just as it would be in an actual flight. Although fuselage test flight data were not provided in Ref. 8, Fig. 33 shows the simulation pitch variation with airspeed. The shallow gradient and decreasing angle of attack as airspeed increases are logical results for V/STOL aircraft fully configured for aerodynamic lifting flight.

Fig. 34 demonstrates the stick variation, displaying the effects of a second simulation with a tail angle matching the test flight conditions (-1.0°) from the original conditions (0.0°). The test flight stick gradient appears to shallow out beyond 180 knots, while the stick gradient of the simulation is nearly linear and positive in this airspeed range. While airflow swirl effects upon the control surfaces have practically no effect at these speeds, inaccuracies in simulation aerodynamic coefficients are magnified with increasing velocity, and are probably the reason for the discrepancy in the simulation and test flight stick gradients.

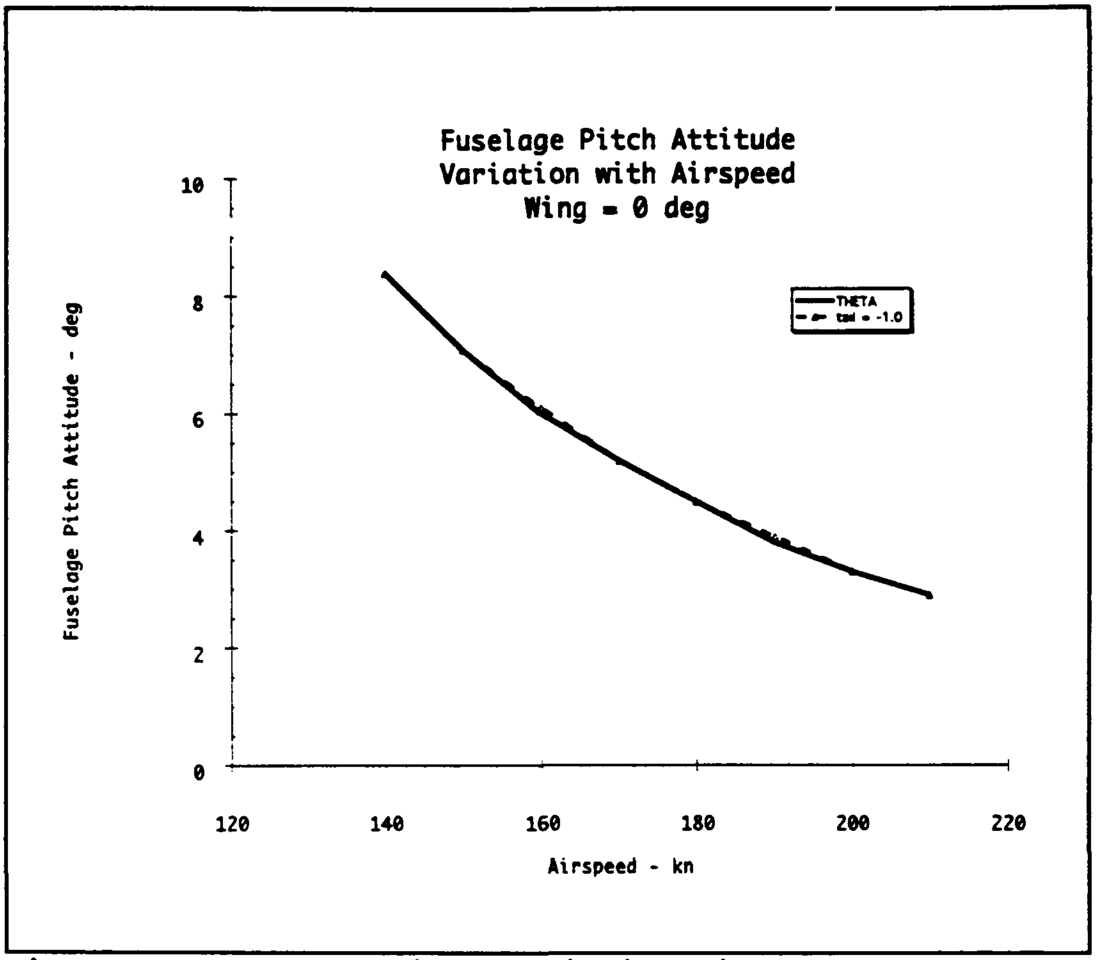


Figure 33 Fuselage Pitch Variation $i_w = 0°$

Fig. 35 shows the effects of changing three different variables within the simulation. Much better agreement between test flight data and simulation data is shown with the changing of the tail incidence in the second simulation to -1.0°. When the simulation CG was moved from 29.4% MAC to 31.0 % MAC, the elevator position was slightly closer still to the test flight data. A fourth simulation, in which the elevator gearing was changed from 6°/in. to 3°/in., has an unexpected result. The data for the new elevator gearing (plotted as

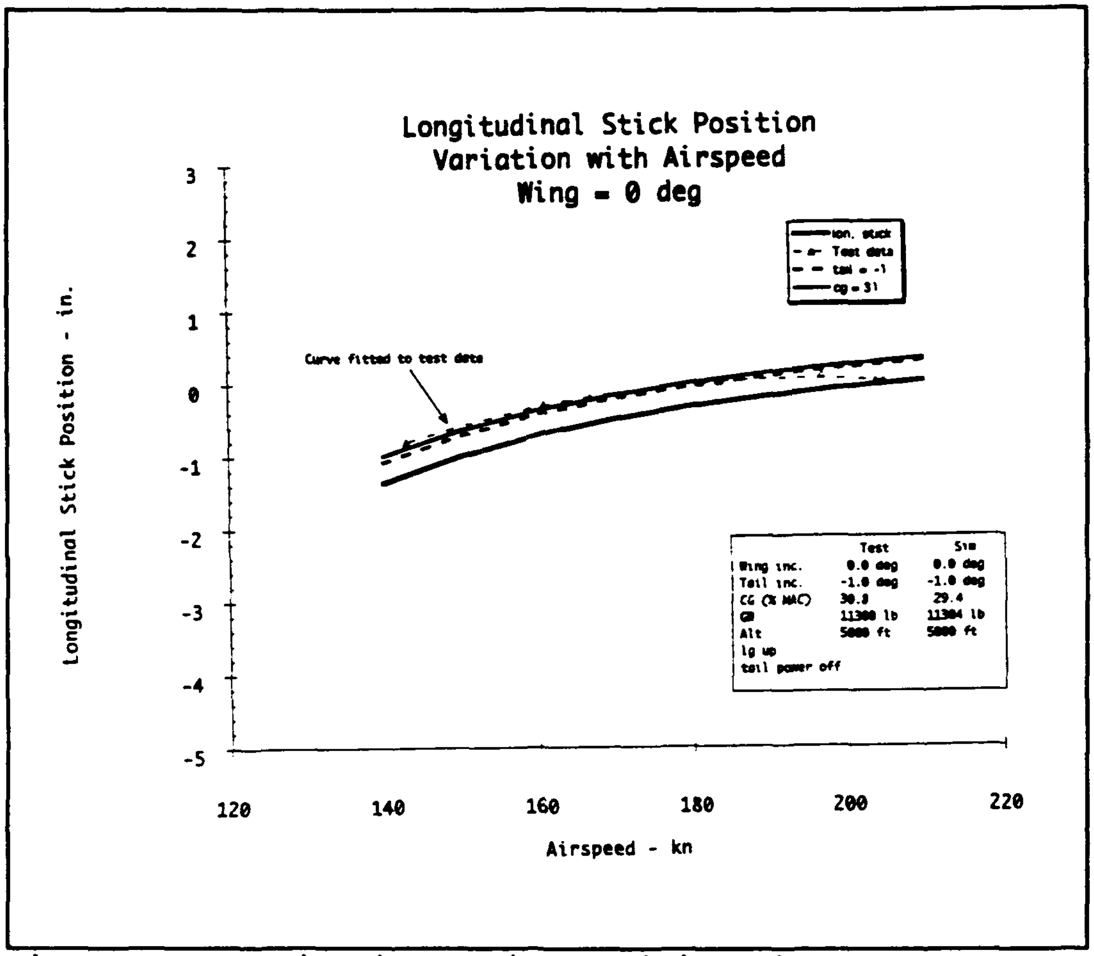


Figure 34 Longitudinal Stick Position $i_w = 0°$

gain=3) is nearly exact to that of the first simulation (plotted as elevator). Their graphs are virtually identical. This would indicate that the CL-84 elevator gearing is not a constant value of 6°/in. or 3°/in., but utilizes some sort of cam within the linkage to change the gain value as wing tilt angle changes. It appears from all five wing angles analyzed that the elevator gearing of the CL-84 starts out around three or four degrees per in. during hover flight conditions, and increases to about six degrees per in. during cruise flight.

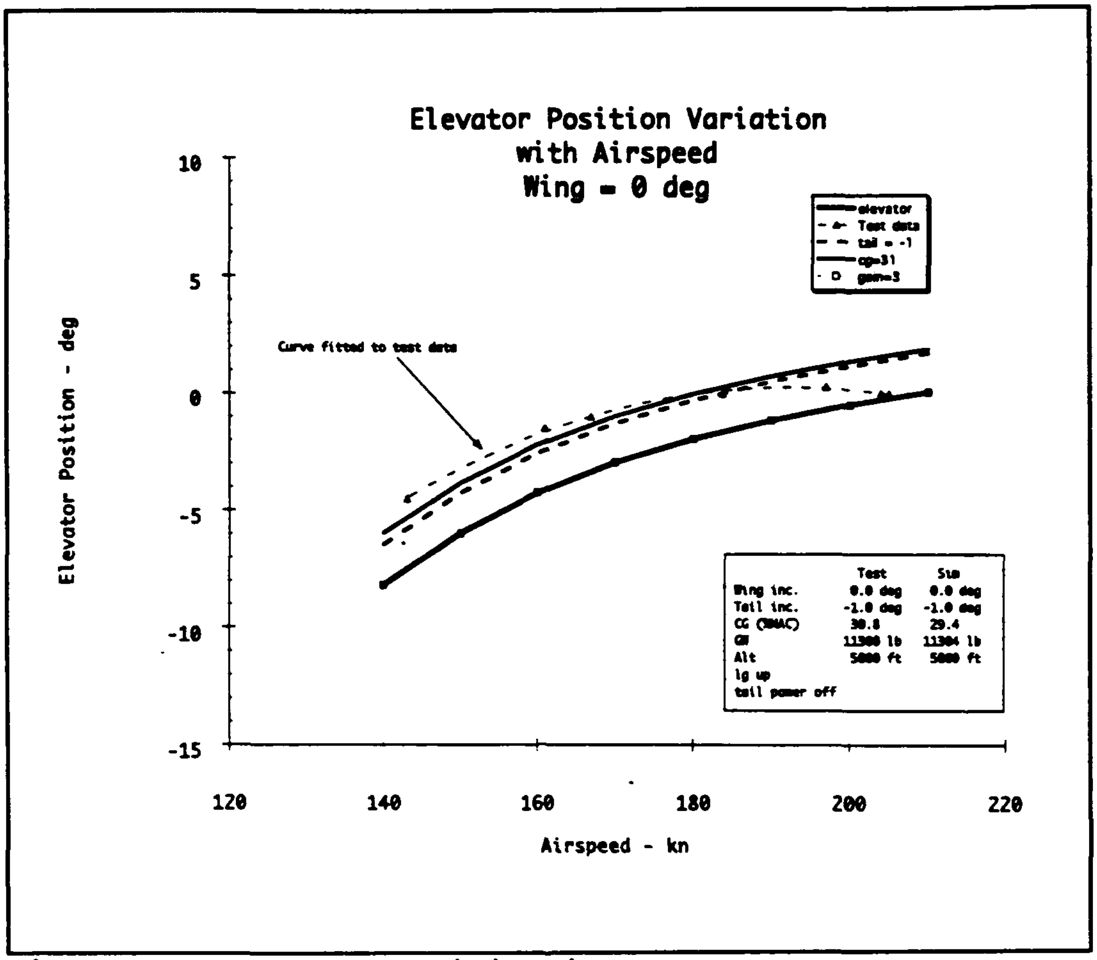


Figure 35 Elevator Position $i_w = 0°$

It has not yet been possible to verify this suggestion. It should be remembered that the CL-84 aircraft is roughly 30 years old and some design data are difficult to verify as a result of this aging time factor.

CONCLUSIONS AND RECOMMENDATIONS

The re-emergence of V/STOL technology has manifested itself in the form of two types of platforms, tilt rotor and tilt wing aircraft. The tilt wing aircraft is competitive with the tilt rotor for a wide variety of military missions and civilian commercial applications. The ability to perform vertical or extremely short takeoffs and landings provides great flexibility in deployment and location of such aircraft.

The complex mathematical coupled-body problem of the equations of motion for the tilt wing system carry over to the flight performance regime. For acceptable handling qualities, a pitch control device, in the form of a tail reaction jet or tail rotors, has been a necessary addition on every tilt rotor aircraft flown and tested to date. It is desirable to eliminate the need for such auxiliary control devices through some advanced control methods, such as the geared flap configuration. To predict the handling qualities of a tilt wing aircraft so configured, the NASA Ames computer code TWANG is used for simulation of aircraft longitudinal stability and performance characteristics.

Modification of TWANG to suit the specific needs of the CL-84 tilt wing aircraft has been accomplished, within the limitations of the simulation computer and the paucity of the CL-84 aerodynamic and performance data.. The CL-84 performance was measured by comparisons of fuselage pitch, longitudinal stick position, and elevator position at five wing tilt angles. Results indicate that the TLTWNG!! modification of TWANG for use with the CL-84 provides accurate simulations of the CL-84 flight characteristics, under the framework of a simplified air flowfield model with no ground effects. The simulation of the two-propeller CL-84 tilt wing aircraft complements that of previous NASA Ames simulations of a four-propeller generic tilt wing aircraft.

Good comparisons of flight characteristics between the CL-84 and the TLTWNG!! simulations came about with only estimations in the aerodynamic coefficients and downwash characteristics of the CL-84. An important next step would be to obtain actual CL-84 wind tunnel data for these figures and examine the results of a second simulation study. Of additional benefit would be additional information on the control system gains of the aircraft simulated. The TLTWNG!! program is sufficiently flexible to be modified to accommodate the specific needs of the inputs for the tilt wing aircraft to be simulated. This would provide more accurate information on the simulated aircraft's handling qualities. A second simulation study could include estimations of the stall boundary in the vicinity of the transition corridor between hovering flight and cruise flight.

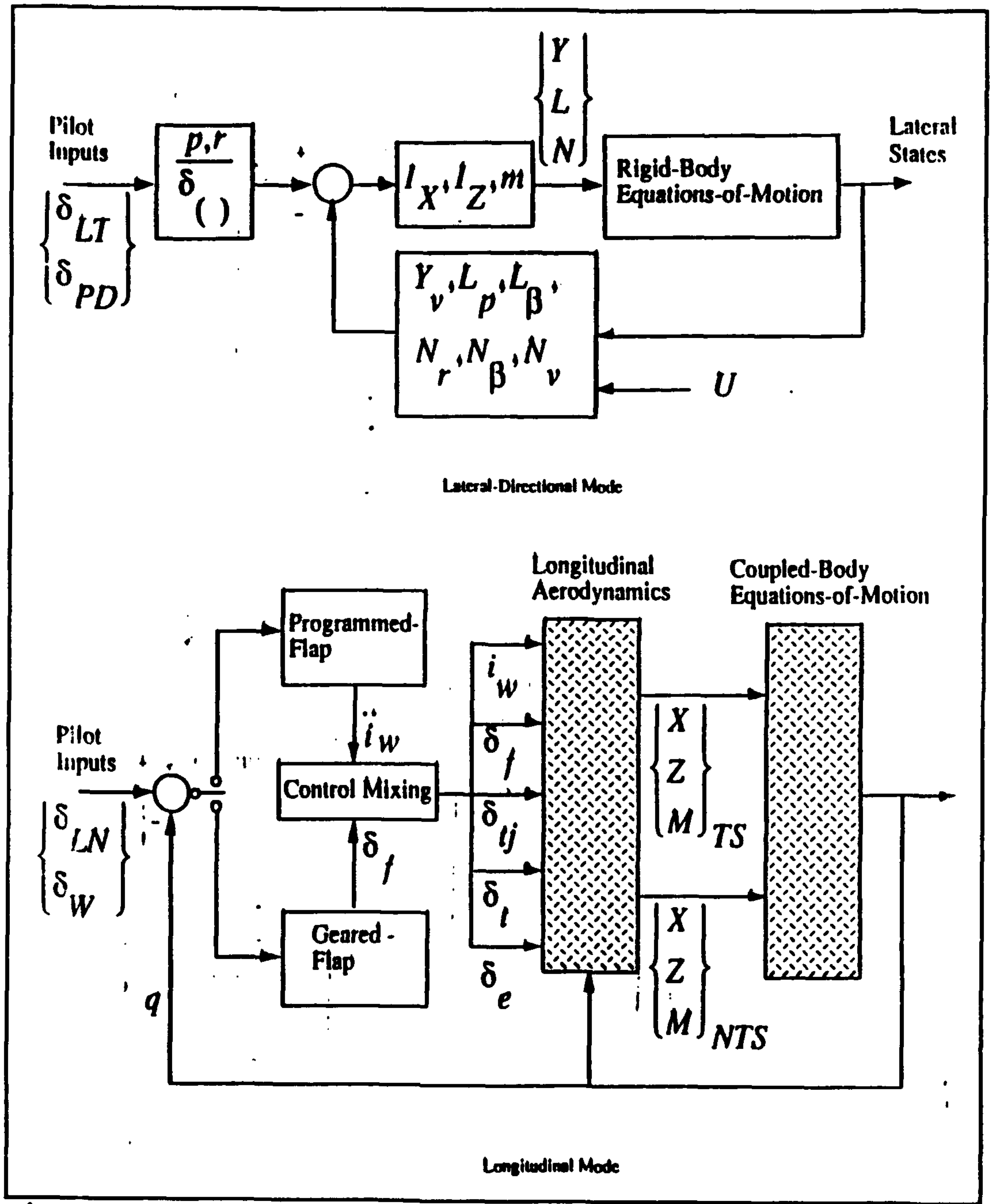


Figure 36 NASA Ames Generic Tilt Wing Aircraft Modes

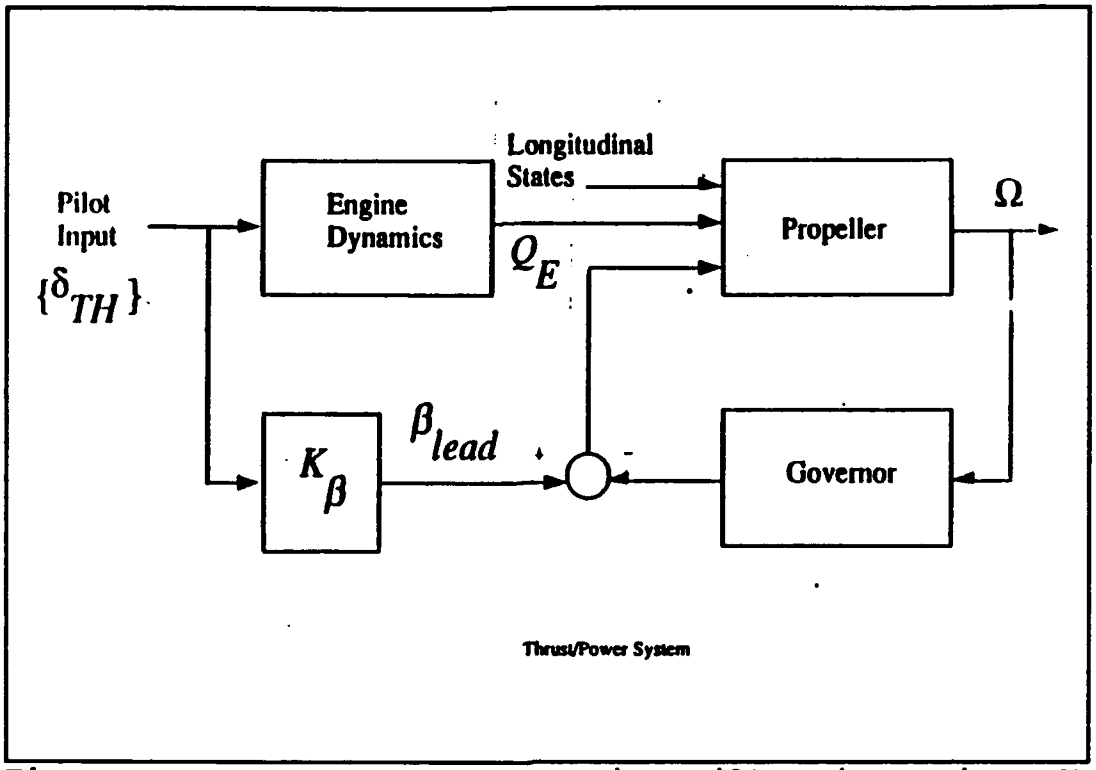


Figure 37 NASA Ames Generic Tilt Wing Aircraft Thrust/Power System

$$
\underbrace{\begin{bmatrix} 1 & 0 & x_{\dot{q}} & 0 \\ 0 & 1 & z_{\dot{q}} & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{FF}
\underbrace{\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix}}_{\dot{X}}
=
\underbrace{\begin{bmatrix} X_u & X_w & x_q & -g \\ Z_u & Z_w & Z_q+U_o & 0 \\ M_u & M_w & M_q & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}}_{AA}
\underbrace{\begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix}}_{X}
+
\underbrace{\begin{bmatrix} x_{\ddot{i}_w} & x_{\dot{i}_w} & x_{i_w} & x_{\delta_f} & x_{\delta_\beta} & 0 & x_{\delta_e} \\ Z_{\ddot{i}_w} & Z_{\dot{i}_w} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}}_{BB}
\underbrace{\begin{bmatrix} \ddot{i}_w \\ \dot{i}_w \\ i_w \\ \delta_f \\ \delta_{\beta_{prop}} \\ \delta_{tail} \\ \delta_e \end{bmatrix}}_{U}
$$

(1) State-space Equations of Motion - Longitudinal Mode

APPENDIX B - TLTWNG!! SAMPLE OUTPUT

USER NAME BILL NIEUSMA CL-84 DATA 10:52:06

RUN IDENTIFICATION

USERS COMMENTS:

USERS COMMENTS:

USERS COMMENTS:

SELECTED OPTIONS

POWER CALCULATED FOR GAMIC= 0.0

PROGRAMED FLAP: ATTENUATION FACTOR= 100.00 LIMIT FLAP DEFL.= 0.00 25.00

PROGRAMMED TAIL INCIDENCE - A/C TRIMMED AT THIC= 0.00 DCX AND IWW VARIED

THETA OPTION ATTITUDE VARIED FOR TRIM AT WING INCIDENCE = 85.1

USERS INPUT CONTROL DATA

VMN -KTS	-20.	DELTAV-KTS	10.	NO. VEL.	6.	ALT. -FT	500.	TEMP-DEG
NX -G	0.00	NZ -G	1.0	ROC-FT/MIN	0.	LG-UP/DN	1.	FLAP OPT
TIO-TAIL OPT.	0.	PCO-PWR OPT.	0.	PCTOMR	95.	THO-FUS.ATT.OPT.	1.	THMX-DEG
THMN-DEG	-70.0	THIC-DEG	0.0	WINCIC-DEG	80.0	BETIC-DEG	12.5	DLSIC-IN
QBDIC-RAD/S**2	0.0	QBIC-RAD/SEC	0.0	STAB. OPTION	0.	PRINT OPT.	0.	GAMIC
VDOTOP	0.	WNGSTK	0.0	AERO PRT	0.	PLROP	0.	DIAGN
ITJET	1.	PCTHP	0.					

WEIGHT DATA REFERENCE

ITEM	WEIGHT-LB	STATION	WATERLINE	IYY
FUSELAGE	3350.	228.0	70.0	15452.
PAYLOAD	2625.	195.7	69.0	562.
FUS. FUEL	0.	0.0	0.0	0.
WING	1237.	192.0	108.0	93.
INBD NACELLES	2613.	158.0	86.0	580.
OUTBD NACELLES	0.	0.0	0.0	0.
INBD WING FUEL	1400.	183.0	107.0	7.
OUTBD WING FUEL	0.	0.0	0.0	0.

IYY/PROP	312.	SHAFT POLAR M	650.
STA WING PIVOT	200.0	WATERLINE WING PIVOT	112.0

1 TRIM PROGRAM INPUT

CONFIGURATION INPUT DATA

SW-FT**2	233.	CBAR-FT	7.00	ASPECT RATIO	4.8	STA CBAR/4	183.2
W.L. CBAR/4	107.0	PROP DIA-FT	14.00	NO. OF PROP	2.	ACTIVITY FACT	90.
SOLIDITY	0.160	AIP-DEG	0.0	STPROP-IN	119.5	WLPROP-IN	86.80
WIMIN-DEG	0.0	ZETA2	0.089	CPOCMX	1.250	ST-FT**2	88.
CBART-FT	5.25	STHT-IN	440.70	WLHT-IN	77.40	XPT	0.25
DLFMIN-DEG	0.0	DLFMAX-DEG	25.0	OMGRIC-FT/SEC	900.	ENGRAT-HP	1150.
DLSMIN-IN	-5.0	DLSMAX-IN	5.0	STNG-IN	122.0	WLNG-IN	7.0
STMG-IN	502.0	WLMG-IN	7.0	DHNGMX-IN	34.0	DHMGMX-IN	34.0
STAFAP-IN	540.0	WLAFAP-IN	207.0	STAWAP-IN	480.2	WLAWAP-IN	207.6
FAB - LB	1250000.	FADLT-LB	0.00	FRMU	0.10	DLBMUR	0.15
XGRIC-FT	0.	BETMIN-DEG	-5.0	IWMX-DEG	100.0	DLFMPV	0.
STRK	250.00						

BASIC AERO COEF INPUT DATA LOC(151) TO (165) ARE AERO COEF. INPUTS

BETMAX-DEG	45.0	ABLADE-/DEG	0.100	CMPRTH-/DEG	0.00000	ALFDL-DEG/IN	6.00
CLOF	0.000	CLAF	0.002	CMOF	0.0000	CMAF	0.0063
CDOF	0.0167	CDOG	0.0150	CMOG	0.0445	EWHO	3.3000
DEDCT	3.90	ETAFS	0.85				

CALCULATED CONFIGURATION DATA

NONTILTING SYSTEM

STFCG	199.19	WLFCG	69.51	HNTS	3.54	XNTS	0.07	WTNTS
MASSNTS	188.	XIYFP	18462.	XIYFO	17366.			

TILTING SYSTEM (WING DOWN)

WIMIN	0.00	STWCG	172.68	WLWCG	96.78	HTS	1.27	XTS
WTTS	5250.00	MASSTS	163.04	XIYWP	1969.	XIYWO	1376.	XWPC4
ZWPC4	-0.42	XLAMO	-29.12	ELWTS	2.61			

TOTAL AIRCRAFT

CGST	186.88	CGWL	82.18	CGSTPC	0.29	CGWLPC	0.30
STPIV	200.00	WLPIV	112.00	SPCTPV	0.45	WPCTPV	-0.06
GROSS WT	11304.	TOT MASS	351.	XIYYDN	19620.	XIYYUP	21823.

PROPELLER

SPR	153.94	AIPR	0.00	STPROP	119.50	WLPROP	86.80	HPROP
XPROP	5.31							

HORIZONTAL TAIL

STHT	440.70	WLHT	77.40	XTAIL	20.06	HT	-2.88
ALTCG	21.15	HTCG	-0.40	VBAR	1.13	XLAMDT	-8.18

TAILJET

TJMOM=	29462.	TJARM=	26.40	TJGRAD=	349.	CTRPWR=	1.35

TRIM OUTPUT/2 PROP/PROGRAM FLAP

JCOUNT = 6
VALID TRIM POINT

--- TRIM STATE ---

	UB	WB	THETA	WINC	FLAP
VALUE (DEG.)	---	---	8.5756	14.0000	4.5600
RATE (FPS OR DEG/S)	133.6245	20.1491	0.0000	0.0000	---
ACCEL (FPS2 OR DEG/S2)	0.0000	-0.0001	0.0428	0.0000	---

--- FLIGHT CONDITION ---

VEQ	80.	V HOR.	80.	ALT.	5000.	DENS.	0.001979
AXN	0.00	AZN	1.00	GAMA	0.00	ROC	0.

--- CONTROLS/SETTINGS ---

WING INC.	14.00	FLAPS	4.56	WIREF	14.00	PRBETA	11.03
TAIL INC.	10.12	ELEVATOR	-3.85	DCX	-0.64		

--- CONFIGURATION ---

GR WT.	11304.	CG STATION	186.88	CG W/LINE	82.18	IYY	19981.

--- PROPELLER ---

BETA	11.03	J	0.497	CT	0.041	CNFPR	0.0059	CMPR	0.0054	CPPR
ALFAP	22.58	RPM	1166.4	THRUST	1172.	FNPR	171.	AMPR	2175.	AMPQD
CTS	0.296	V IND	13.3	V SLIP	158.5	QPROP	16849.	TMHUB	3916.	HPREQ

--- WING ---

WINC	14.00	QASLIP	25.69	ALFATS	22.58	CLS	1.761	CXS	0.0441	CMS
FLAP	4.56	QSLIP	24.85	ALFAE	17.65	CLWAE	1.734	CDWAE	0.1989	CMWAE
AKA	0.9611	AK1	0.5647	SIS	0.786	CLWA	2.127	CDWA	0.2874	CMWA
ALFAEM	30.13									

--- FUSELAGE ---

ATTITUDE	8.58	Q	18.07	LDG GR	0.0		
FUS ALFA	8.58	CLF	0.000	CDF	0.0167	CMF	0.0000

--- TAIL ---

TL INC	10.12	ELEV.	-3.85	ALFAT	6.42	CLT	0.276	CDT	0.0274	CMT	0.0383
QBART	22.673	PHIWAK	-2.488	EWH	12.276	XKI	8.307	EPSMX	14.2683	ETASS	0.9602

--- FORCES AND MOMENTS ---

PROPELLER	THRUST	1172.	FNPR	171.	TMHUB	3916.	TORQUE	16849.
TILTING SYSTEM	FXTS	1835.	FZTS	-10395.	TMTC4	7157.	TMTS	22205.
NON-TILTING SYSTEM	FXFUSE	-60.	FZFUSE	-75.	TMF	1388.		
TAIL	FXTAIL	-90.	FZTAIL	-543.	TMTAIL	-10750.	TMFT	-4997.
TAIL JET	FZTJET	-165.	TMTJET	4365.	TJBIAS	0.	TJMBIAS	0.
PIVOT	FXPIV	-1052.	FZPIV	5203.	TMPIV	-8610.	TMPO	0.
TOTALS	FAX	1685.	FAZ	-11178.	EMTS	8612.	EMNTS	-8597.

TRIM OUTPUT/2 PROP/PROGRAM FLAP

JCOUNT = 4
VALID TRIM POINT

--- TRIM STATE ---

	UB	WB	THETA	WINC	FLAP
VALUE (DEG.)	---	---	4.5328	14.0000	4.5600
RATE (FPS OR DEG/S)	151.5516	12.0137	0.0000	0.0000	---
ACCEL (FPS2 OR DEG/S2)	0.0005	-0.0003	-0.0358	0.0000	---

--- FLIGHT CONDITION ---

VEQ	90.	V HOR.	90.	ALT.	5000.	DENS.	0.001979
AXN	0.00	AZN	1.00	GAMA	0.00	ROC	0.

--- CONTROLS/SETTINGS ---

WING INC.	14.00	FLAPS	4.56	WIREF	14.00	PRBETA	11.70
TAIL INC.	10.12	ELEVATOR	-1.33	DCX	-0.22		

--- CONFIGURATION ---

GR WT.	11304.	CG STATION	186.88	CG W/LINE	82.18	IYY	19981.

--- PROPELLER ---

BETA	11.70	J	0.559	CT	0.034	CNFPR	0.0062	CMPR	0.0044	CPPR
ALFAP	18.53	RPM	1166.4	THRUST	965.	FNPR	179.	AMPR	1766.	AMPQD
CTS	0.215	V IND	10.0	V SLIP	169.8	QPROP	16844.	TMHUB	3482.	HPREQ

--- WING ---

WINC	14.00	QASLIP	29.14	ALFATS	18.53	CLS	1.593	CXS	0.0302	CMS
FLAP	4.56	QSLIP	28.54	ALFAE	15.25	CLWAE	1.558	CDWAE	0.1609	CMWAE
AKA	0.9731	AK1	0.5647	SIS	0.789	CLWA	1.804	CDWA	0.2128	CMWA
ALFAEM	30.13									

--- FUSELAGE ---

ATTITUDE	4.53	Q	22.87	LDG GR	0.0		
FUS ALFA	4.53	CLF	0.000	CDF	0.0167	CMF	0.0000

--- TAIL ---

TL INC	10.12	ELEV.	-1.33	ALFAT	3.41	CLT	0.171	CDT	0.0168	CMT	0.0151
QBART	25.662	PHIWAK	-0.495	EWH	11.243	XKI	6.314	EPSMX	12.2183	ETASS	0.9921

--- FORCES AND MOMENTS ---

PROPELLER	THRUST	965.	FNPR	179.	TMHUB	3482.	TORQUE	16844.
TILTING SYSTEM	FXTS	1061.	FZTS	-10785.	TMTC4	5210.	TMTS	20878.
NON-TILTING SYSTEM	FXFUSE	-85.	FZFUSE	-50.	TMF	768.		
TAIL	FXTAIL	-82.	FZTAIL	-377.	TMTAIL	-7614.	TMFT	-5340.
TAIL JET	FZTJET	-57.	TMTJET	1507.	TJBIAS	0.	TJMBIAS	0.
PIVOT	FXPIV	-646.	FZPIV	5551.	TMPIV	-7429.	TMPO	0.
TOTALS	FAX	893.	FAZ	-11269.	EMTS	7428.	EMNTS	-7441.

TRIM OUTPUT/2 PROP/PROGRAM FLAP

JCOUNT = 5
VALID TRIM POINT

--- TRIM STATE

	UB	WB	THETA	WINC	FLAP
VALUE (DEG.)	---	---	1.1943	14.0000	4.5600
RATE (FPS OR DEG/S)	168.8822	3.5205	0.0000	0.0000	---
ACCEL (FPS2 OR DEG/S2)	0.0000	0.0000	-0.0339	0.0000	---

--- FLIGHT CONDITION

VEQ	100.	V HOR.	100.	ALT.	5000.	DENS.	0.001979
AXN	0.00	AZN	1.00	GAMA	0.00	ROC	0.

--- CONTROLS/SETTINGS

WING INC.	14.00	FLAPS	4.56	WIREF	14.00	PRBETA	12.52
TAIL INC.	10.12	ELEVATOR	0.73	DCX	0.12		

--- CONFIGURATION

GR WT.	11304.	CG STATION	186.88	CG W/LINE	82.18	IYY	19981.

--- PROPELLER

BETA	12.52	J	0.621	CT	0.029	CNFPR	0.0064	CMPR	0.0035	CPPR
ALFAP	15.19	RPM	1166.4	THRUST	842.	FNPR	184.	AMPR	1421.	AMPQD
CTS	0.162	V IND	8.0	V SLIP	183.3	QPROP	18149.	TMHUB	3059.	HPREQ

--- WING

WINC	14.00	QASLIP	33.71	ALFATS	15.19	CLS	1.411	CXS	0.0236	CMS
FLAP	4.56	QSLIP	33.26	ALFAE	12.87	CLWAE	1.370	CDWAE	0.1318	CMWAE
AKA	0.9803	AK1	0.5647	SIS	0.791	CLWA	1.554	CDWA	0.1600	CMWA
ALFAEM	30.13									

--- FUSELAGE

ATTITUDE	1.19	Q	28.24	LDG GR	0.0		
FUS ALFA	1.19	CLF	0.000	CDF	0.0167	CMF	0.0000

--- TAIL

TL INC	10.12	ELEV.	0.73	ALFAT	1.03	CLT	0.092	CDT	0.0135	CMT	-0.0036
QBART	29.381	PHIWAK	1.325	EWH	10.288	XKI	4.494	EPSMX	10.7003	ETASS	0.9835

--- FORCES AND MOMENTS

PROPELLER	THRUST	842.	FNPR	184.	TMHUB	3059.	TORQUE	18149.
TILTING SYSTEM	FXTS	417.	FZTS	-11089.	TMTC4	3666.	TMTS	19819.
NON-TILTING SYSTEM	FXFUSE	-110.	FZFUSE	-16.	TMF	-40.		
TAIL	FXTAIL	-72.	FZTAIL	-228.	TMTAIL	-4825.	TMFT	-5696.
TAIL JET	FZTJET	31.	TMTJET	-831.	TJBIAS	0.	TJMBIAS	0.
PIVOT	FXPIV	-307.	FZPIV	5840.	TMPIV	-6540.	TMP0	0.
TOTALS	FAX	236.	FAZ	-11302.	EMTS	6539.	EMNTS	-6550.

TRIM OUTPUT/2 PROP/PROGRAM FLAP

JCOUNT = 4
VALID TRIM POINT

--- TRIM STATE ---

	UB	WB	THETA	WINC	FLAP
VALUE (DEG.)	---	---	-1.5423	14.0000	4.5600
RATE (FPS OR DEG/S)	185.7435	-5.0008	0.0000	0.0000	---
ACCEL (FPS2 OR DEG/S2)	-0.0002	-0.0001	-0.0066	0.0000	---

--- FLIGHT CONDITION ---

VEQ	110.	V HOR.	110.	ALT.	5000.	DENS.	0.001979
AXN	0.00	AZN	1.00	GAMA	0.00	ROC	0.

--- CONTROLS/SETTINGS ---

WING INC.	14.00	FLAPS	4.56	WIREF	14.00	PRBETA	14.09
TAIL INC.	10.12	ELEVATOR	2.34	DCX	0.39		

--- CONFIGURATION ---

GR WT.	11304.	CG STATION	186.88	CG W/LINE	82.18	IYY	19981.

--- PROPELLER ---

BETA	14.09	J	0.683	CT	0.028	CNFPR	0.0067	CMPR	0.0028	CPPR
ALFAP	12.46	RPM	1166.4	THRUST	795.	FNPR	194.	AMPR	1110.	AMPQD
CTS	0.131	V IND	7.0	V SLIP	198.5	QPROP	17109.	TMHUB	2638.	HPREQ

--- WING ---

WINC	14.00	QASLIP	39.33	ALFATS	12.46	CLS	1.235	CXS	0.0215	CMS
FLAP	4.56	QSLIP	38.98	ALFAE	10.68	CLWAE	1.194	CDWAE	0.1131	CMWAE
AKA	0.9842	AK1	0.5647	SIS	0.792	CLWA	1.336	CDWA	0.1270	CMWA
ALFAEM	30.13									

--- FUSELAGE ---

ATTITUDE	-1.54	Q	34.17	LDG GR	0.0		
FUS ALFA	-1.54	CLF	0.000	CDF	0.0167	CMF	0.0000

--- TAIL ---

TL INC	10.12	ELEV.	2.34	ALFAT	-0.82	CLT	0.033	CDT	0.0156	CMT	-0.0184
QBART	33.962	PHIWAK	2.884	EWH	9.394	XKI	2.935	EPSMX	9.5224	ETASS	0.9523

--- FORCES AND MOMENTS ---

PROPELLER	THRUST	795.	FNPR	194.	TMHUB	2638.	TORQUE	17109.
TILTING SYSTEM	FXTS	-108.	FZTS	-11339.	TMTC4	2270.	TMTS	18823.
NON-TILTING SYSTEM	FXFUSE	-132.	FZFUSE	26.	TMF	-1013.		
TAIL	FXTAIL	-64.	FZTAIL	-87.	TMTAIL	-2219.	TMFT	-5886.
TAIL JET	FZTJET	101.	TMTJET	-2654.	TJBIAS	0.	TJMBIAS	0.
PIVOT	FXPIV	-33.	FZPIV	6091.	TMPIV	-5715.	TMPO	0.
TOTALS	FAX	-304.	FAZ	-11300.	EMTS	5715.	EMNTS	-5‾ 7.

```
                                            TRIM OUTPUT/2 PROP/PROGRAM FLAP

 JCOUNT =  4
 VALID TRIM POINT


--- TRIM STATE ----------------------------------------------------------------------------------------
                                 UB          WB         THETA       WINC        FLAP
 VALUE (DEG.)                   ---         ---        -3.8382     14.0000     4.5600
 RATE  (FPS OR DEG/S)       202.2481    -13.5679      0.0000      0.0000       ---
 ACCEL (FPS2 OR DEG/S2)       0.0008     -0.0002      0.0116      0.0000       ---

--- FLIGHT CONDITION ----------------------------------------------------------------------------------
VEQ        120.       V HOR.     120.       ALT.       5000.      DENS.  0.001979
AXN        0.00       AZN        1.00       GAMA        0.00      ROC           0.

--- CONTROLS/SETTINGS ---------------------------------------------------------------------------------
WING INC.   14.00     FLAPS        4.56     WIREF        14.00    PRBETA     15.64
TAIL INC.   10.12     ELEVATOR     3.63     DCX           0.60

--- CONFIGURATION -------------------------------------------------------------------------------------
GR WT.   11304.       CG STATION  186.88    CG W/LINE    82.18  IYY      19981.

---  PROPELLER ----------------------------------------------------------------------------------------
BETA      15.64     J          0.745     CT        0.028     CNFPR   0.0069     CMPR    0.0022     CPPR
ALFAP     10.16     RPM       1166.4     THRUST    800.      FNPR      198.     AMPR      874.     AMPQD
CTS       0.113     V IND        6.5     V SLIP    214.6     QPROP   17392.     TMHUB    2289.     HPREQ

---  WING ---------------------------------------------------------------------------------------------
WINC      14.00     QASLIP    45.86     ALFATS   10.16     CLS      1.082     CXS     0.0211     CMS
FLAP       4.56     QSLIP     45.58     ALFAE     8.75     CLWAE    1.045     CDWAE   0.1026     CMWAE
AKA      0.9865     AK1      0.5647     SIS      0.791     CLWA     1.153     CDWA    0.1091     CMWA
ALFAEM    30.13

---  FUSELAGE -----------------------------------------------------------------------------------------
ATTITUDE   -3.84     Q            40.67     LDG GR         0.0
FUS ALFA   -3.84     CLF          0.000     CDF         0.0167     CMF         0.0000

---  TAIL ---------------------------------------------------------------------------------------------
TL INC    10.12   ELEV.      3.63   ALFAT    -2.27   CLT     -0.011   CDT     0.0185   CMT    -0.0303
QBART    39.280   PHIWAK    4.220   EWH      8.553   XKI      1.599   EPSMX   8.5625   ETASS   0.9073

---  FORCES AND MOMENTS -----------------------------------------------------------------------------
PROPELLER            THRUST     800.      FNPR       198.     TMHUB     2289.     TORQUE   17392.
TILTING SYSTEM       FXTS      -549.      FZTS    -11562.     TMTC4      938.     TMTS     17846.
NON-TILTING SYSTEM   FXFUSE    -154.      FZFUSE      76.     TMF      -2155.
TAIL                 FXTAIL     -54.      FZTAIL      52.     TMTAIL     339.     TMFT     -5929.
TAIL JET             FZTJET     156.      TMTJET   -4112.     TJBIAS       0.     TJMBIAS      0.
PIVOT                FXPIV      198.      FZPIV     6324.     TMPIV    -4905.     TMPO         0.
TOTALS               FAX       -756.      FAZ     -11279.     EMTS      4906.     EMNTS    -4902.
```

TRIM OUTPUT/2 PROP/PROGRAM FLAP

JCOUNT = 5
VALID TRIM POINT

--- TRIM STATE ---

	UB	WB	THETA	WINC	FLAP
VALUE (DEG.)	---	---	-5.7308	14.0000	4.5600
RATE (FPS OR DEG/S)	218.4972	-21.9258	0.0000	0.0000	---
ACCEL (FPS2 OR DEG/S2)	0.0005	0.0010	0.0503	0.0000	---

--- FLIGHT CONDITION ---

VEQ	130.	V HOR.	130.	ALT.	5000.	DENS.	0.001979
AXN	0.00	AZN	1.00	GAMA	0.00	ROC	0.

--- CONTROLS/SETTINGS ---

WING INC.	14.00	FLAPS	4.56	WIREF	14.00	PRBETA	17.09
TAIL INC.	10.12	ELEVATOR	4.52	DCX	0.75		

--- CONFIGURATION ---

GR WT.	11304.	CG STATION	186.88	CG W/LINE	82.18	IYY	19981.

--- PROPELLER ---

BETA	17.09	J	0.807	CT	0.029	CNFPR	0.0069	CMPR	0.0017	CPPR	
ALFAP	8.27	RPM	1166.4	THRUST	829.	FNPR	198.	AMPR	701.	AMPQD	
CTS	0.101	V IND	6.2	V SLIP	231.2	QPROP	20578.	TMHUB	2008.	HPREQ	

--- WING ---

WINC	14.00	QASLIP	53.11	ALFATS	8.27	CLS	0.952	CXS	0.0209	CMS	
FLAP	4.56	QSLIP	52.89	ALFAE	7.13	CLWAE	0.919	CDWAE	0.0951	CMWAE	
AKA	0.9880	AK1	0.5647	SIS	0.791	CLWA	1.008	CDWA	0.1006	CMWA	
ALFAEM	30.13										

--- FUSELAGE ---

ATTITUDE	-5.73	Q	47.73	LDG GR	0.0		
FUS ALFA	-5.73	CLF	0.000	CDF	0.0167	CMF	0.0000

--- TAIL ---

TL INC	10.12	ELEV.	4.52	ALFAT	-3.32	CLT	-0.044	CDT	0.0197	CMT	-0.0386
QBART	45.218	PHIWAK	5.332	EWH	7.704	XKI	0.487	EPSMX	7.7820	ETASS	0.8634

--- FORCES AND MOMENTS ---

PROPELLER	THRUST	829.	FNPR	198.	TMHUB	2008.	TORQUE	20578.
TILTING SYSTEM	FXTS	-919.	FZTS	-11760.	TMTC4	-414.	TMTS	16806.
NON-TILTING SYSTEM	FXFUSE	-174.	FZFUSE	133.	TMF	-3438.		
TAIL	FXTAIL	-36.	FZTAIL	186.	TMTAIL	2820.	TMFT	-5736.
TAIL JET	FZTJET	194.	TMTJET	-5118.	TJBIAS	0.	TJMBIAS	0.
PIVOT	FXPIV	395.	FZPIV	6536.	TMPIV	-4018.	TMPO	0.
TOTALS	FAX	-1128.	FAZ	-11247.	EMTS	4019.	EMNTS	-4002.

Trim Summary Output

airsp kts	theta	winc	flap	trim status	tail inc	DCX	betapr	WIREFO	THRUST	AMTT	req hpower	TMTJET	pivot moment	ROC	Al
80	8.6	14.00	4.6	VALID	10.1	-0.64	11.03	14.00	1172	0	379	4365	-8610	0	
90	4.5	14.00	4.6	VALID	10.1	-0.22	11.70	14.00	965	0	379	1507	-7429	0	
100	1.2	14.00	4.6	VALID	10.1	0.12	12.52	14.00	842	0	408	-831	-6540	0	
110	-1.5	14.00	4.6	VALID	10.1	0.39	14.09	14.00	795	0	385	-2654	-5715	0	
120	-3.8	14.00	4.6	VALID	10.1	0.60	15.64	14.00	800	0	391	-4112	-4905	0	
130	-5.7	14.00	4.6	VALID	10.1	0.75	17.09	14.00	829	0	463	-5118	-4018	0	

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16. Interview between Mr. William Hindson, NASA Ames test pilot, and the author, March 1992.

17. Interview with Mr. Gary B. Churchill, NASA Ames, and the author, March 1992.

18. Interview with Mr. William Decker, NASA Ames, and others, and the author, March 1992.

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